

Presented at The Ohio State University, Aerospace Engineering and Aviation Spring
29002 Seminar Series, April 25, 2002

**Glenn-HT: The NASA Glenn Research Center General Multi-Block Navier-Stokes
Heat Transfer Code**

Raymond E. Gaugler, Chief, Turbine Branch

For the last several years, Glenn-HT, a three-dimensional (3D) Computational Fluid Dynamics (CFD) computer code for the analysis of gas turbine flow and convective heat transfer has been evolving at the NASA Glenn Research Center. The code is unique in the ability to give a highly detailed representation of the flow field very close to solid surfaces in order to get accurate representation of fluid heat transfer and viscous shear stresses. The code has been validated and used extensively for both internal cooling passage flow and for hot gas path flows, including detailed film cooling calculations and complex tip clearance gap flow and heat transfer. In its current form, this code has a multiblock grid capability and has been validated for a number of turbine configurations. The code has been developed and used primarily as a research tool, but it can be useful for detailed design analysis. In this presentation, the code is described and examples of its validation and use for complex flow calculations are presented, emphasizing the applicability to turbomachinery.

(2)

Glenn-HT: The NASA Glenn Research Center General Multi-Block Navier-Stokes Heat Transfer Code

By

***Raymond E. Gaugler
Chief, Turbine Branch
NASA Glenn Research Center***

***Presented at
Ohio State University
Aerospace Engineering and Aviation
Spring 2002 Seminar Series
April 25, 2002***

***Glenn Research Center
TURBINE BRANCH***



at Lewis Field

Glenn-HT: The NASA Glenn Research Center General Multi-Block Navier-Stokes Heat Transfer Code

OUTLINE

- **NASA Glenn Turbine Branch**
- **Glenn-HT History**
- **Glenn-HT Capabilities**
- **Glenn-HT Sample Validation Cases**
- **Glenn-HT Future Direction**

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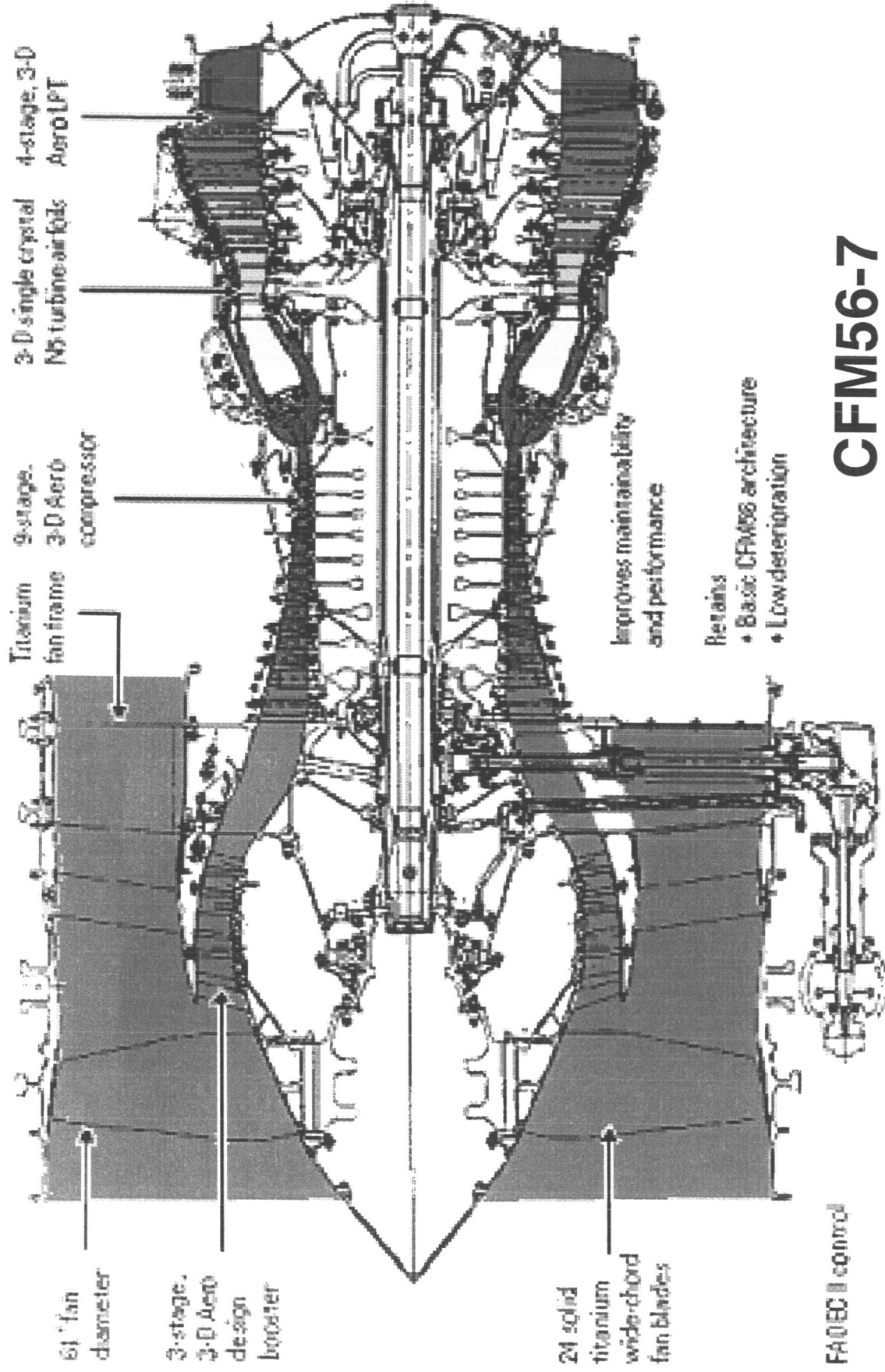
The image displays two technical drawings of mechanical models, labeled PW4000 and PW4168. The drawings are oriented vertically, with the labels on the left and the models on the right. The PW4000 model is shown in a side view, highlighting its internal components, including a large cylindrical tank, a complex network of pipes, and a series of interconnected mechanical parts. The PW4168 model is shown in a similar side view, but with a more complex internal structure, featuring a large cylindrical tank, a series of interconnected mechanical parts, and a prominent vertical pipe. Both models are depicted with detailed line work, indicating their mechanical nature.

GP7200 for A3XX

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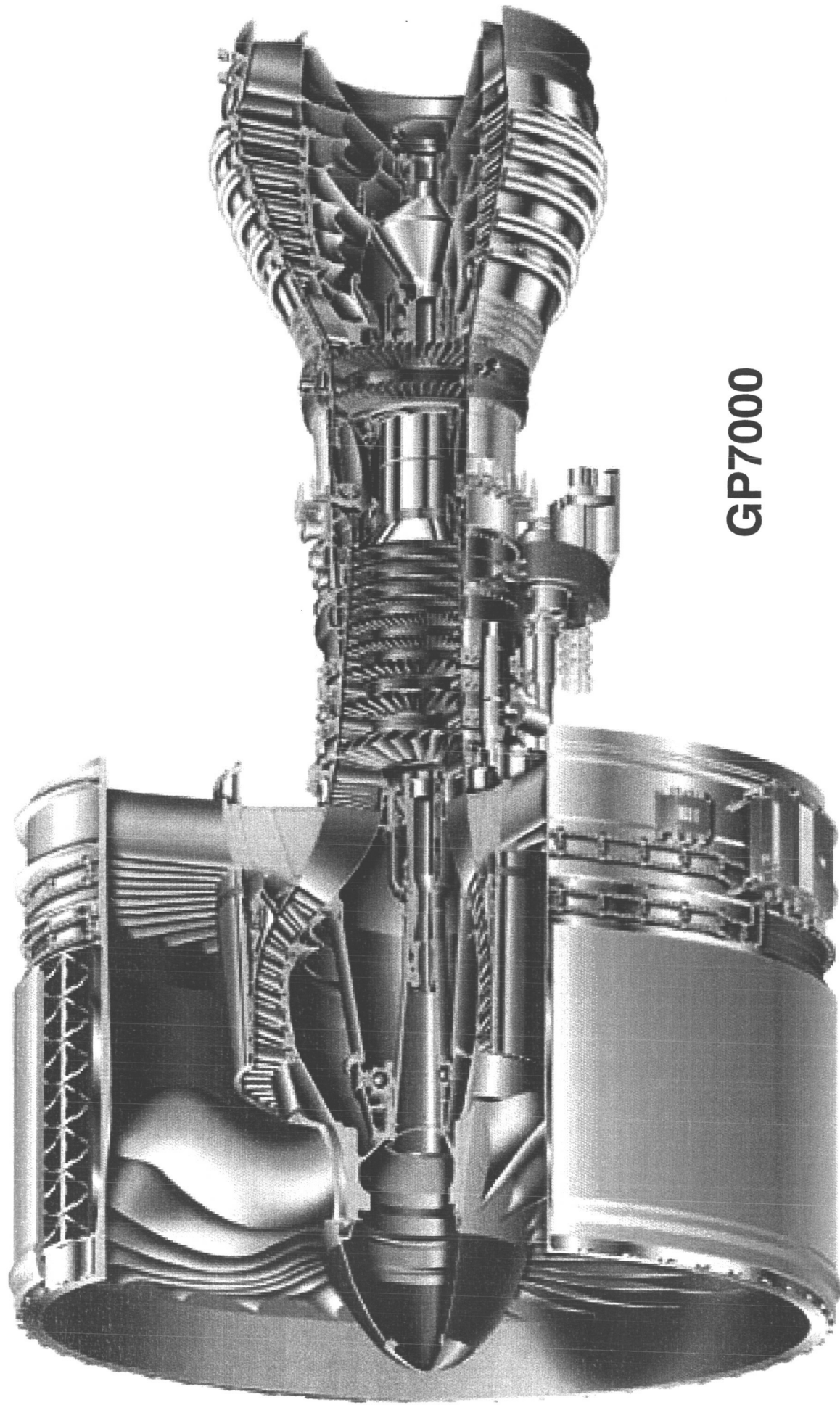
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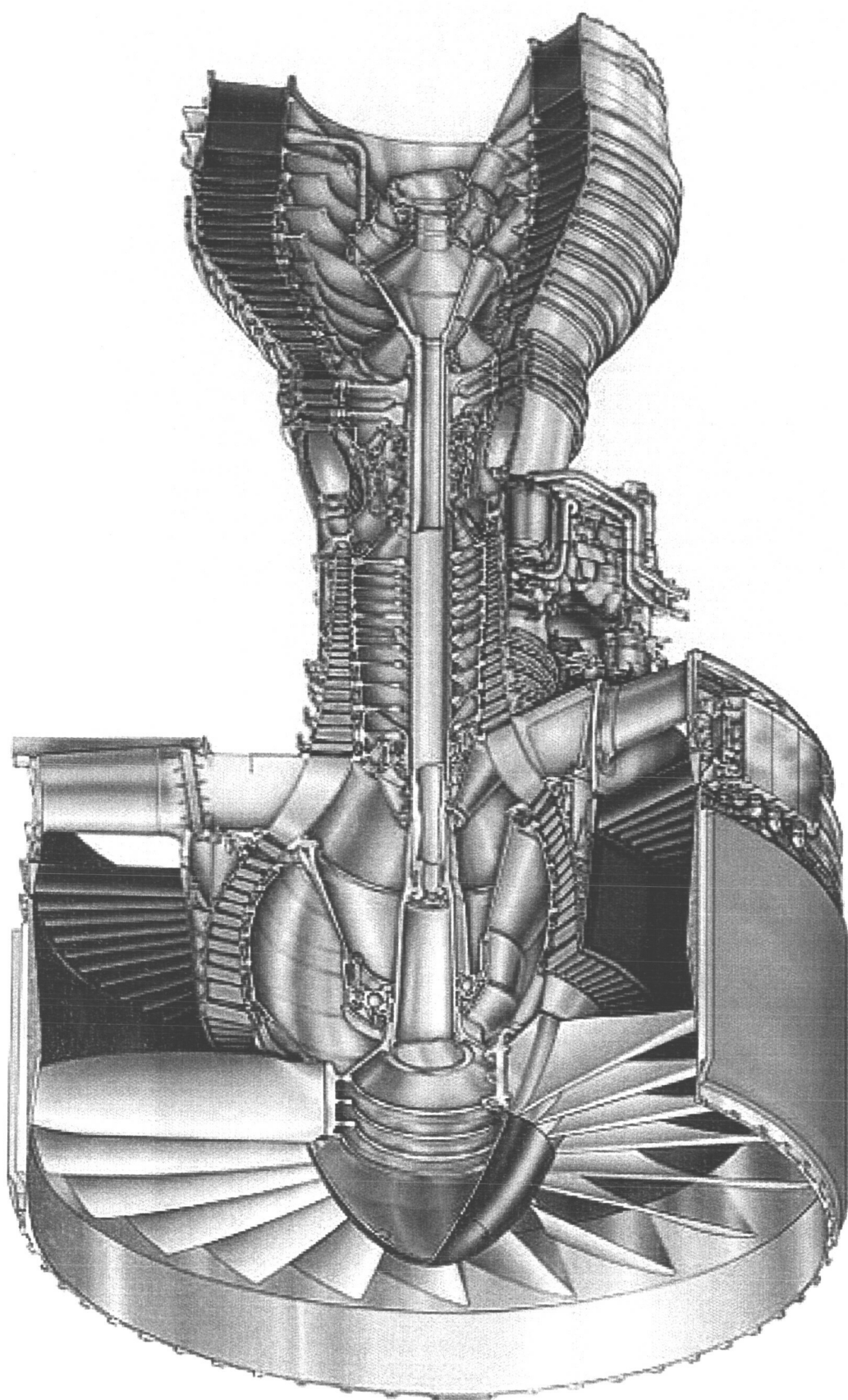


GP7000



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PW4000-112

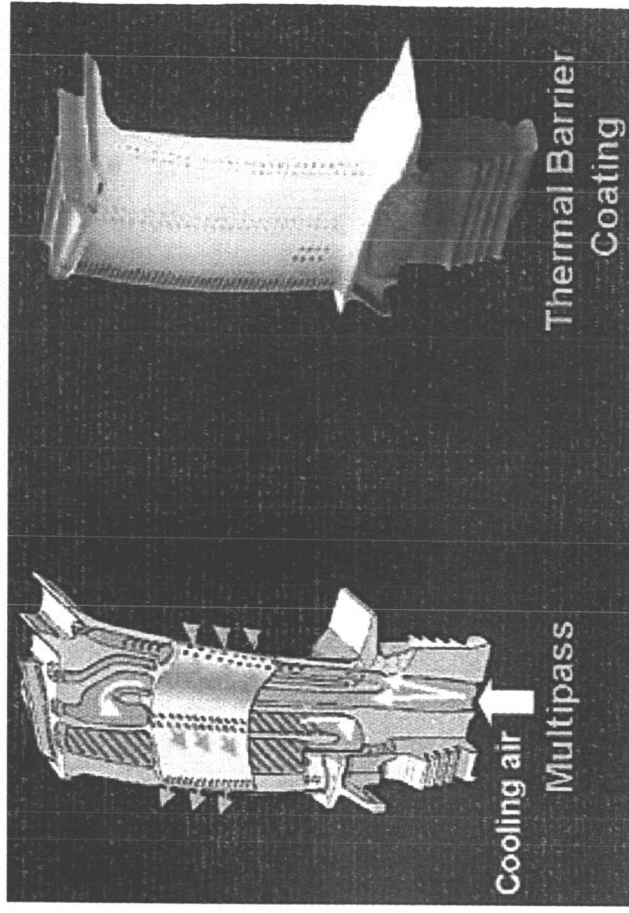
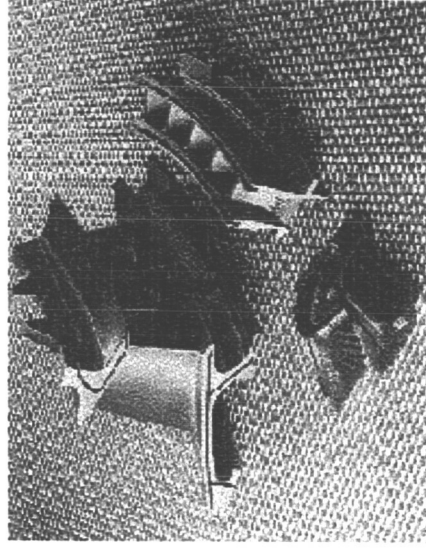
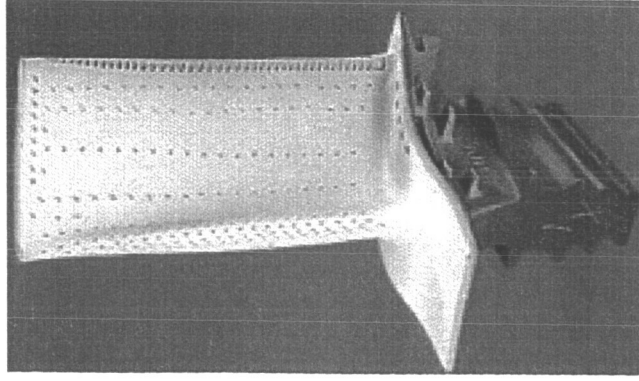
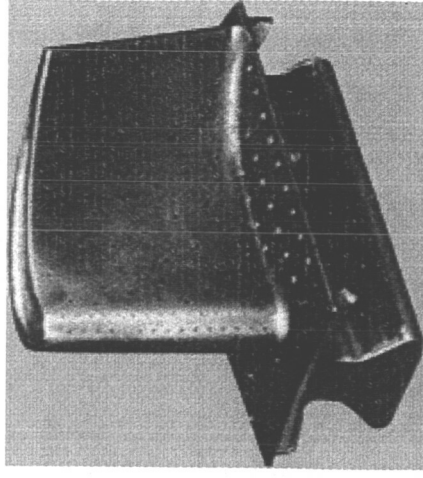
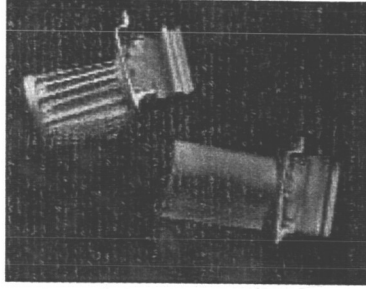
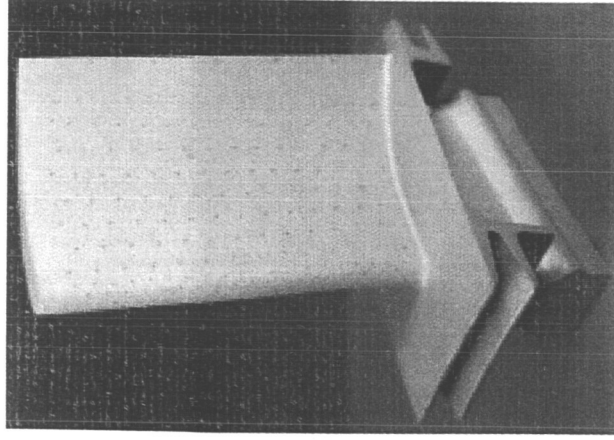
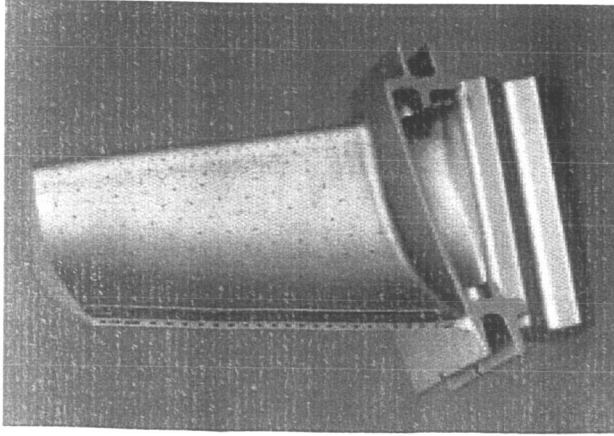


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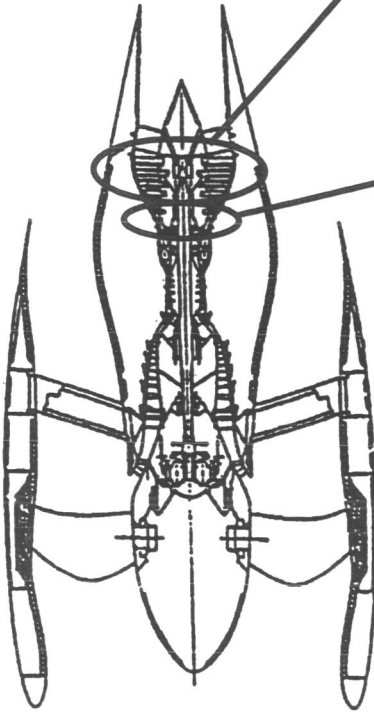
Some Typical Modern Cooled Turbine Blades



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Aerodynamics & Heat Transfer Research for Turbines

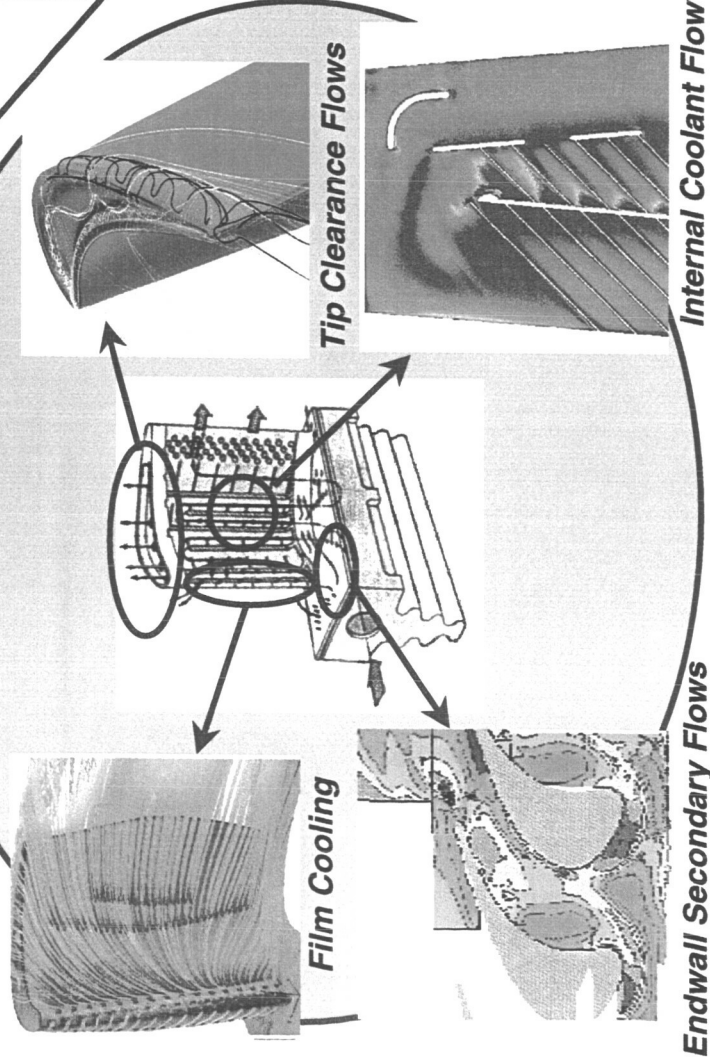
Experiments and Computations for:

- High-Pressure Turbine (HPT) - *Improved computational models for losses, heat transfer, and coolant flow.*
- Low-Pressure Turbine (LPT) - *Understand, model, and control the physical mechanisms responsible for high loss variations*

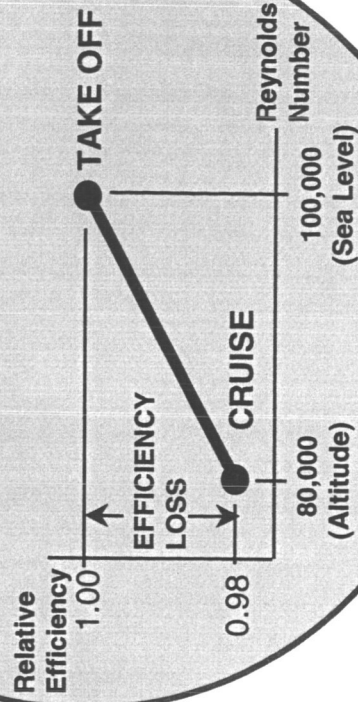
OUTCOME:

- Reduced design cycle time & cost
- Improved component robustness & efficiency

SOME CRITICAL HPT MODELING ISSUES



CRITICAL LPT MODELING ISSUES



Endwall Secondary Flows

Internal Coolant Flow

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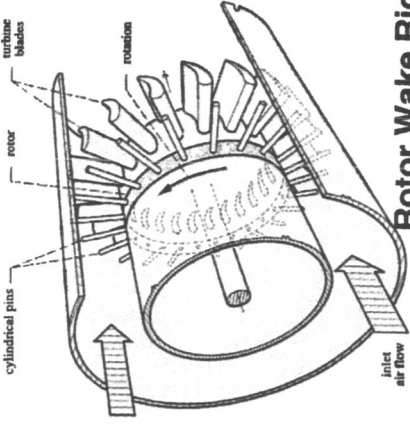
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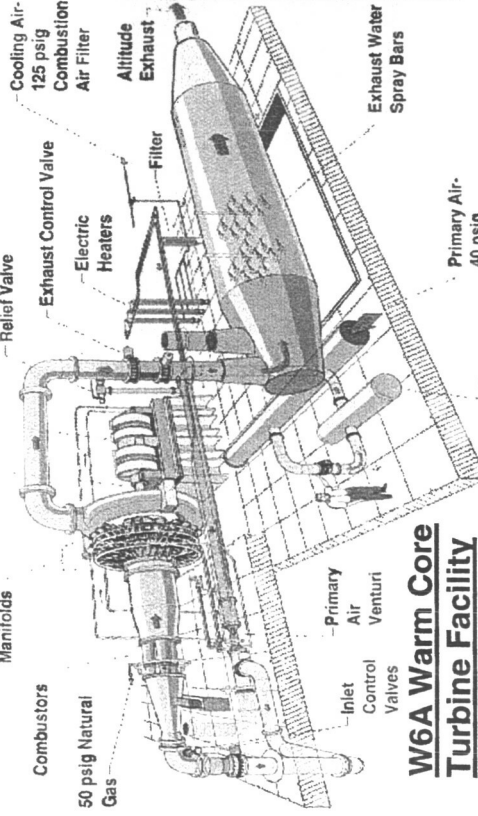
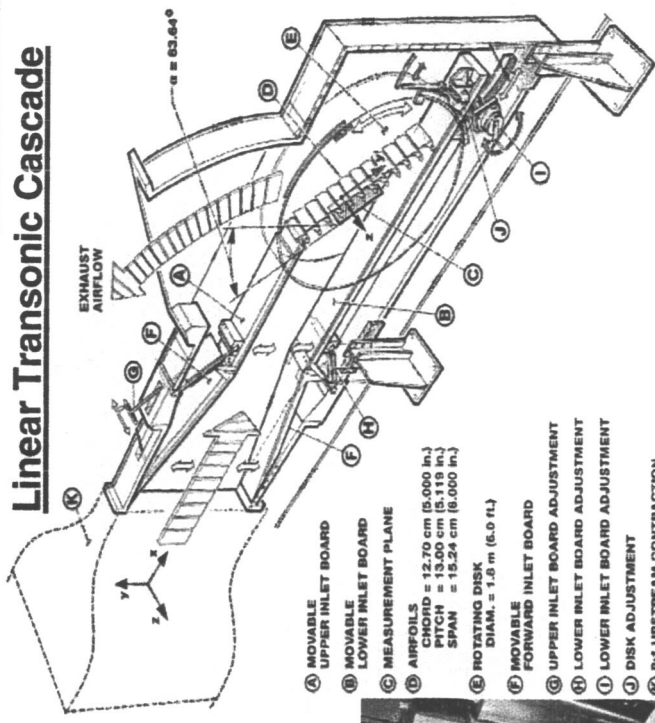
EXPERIMENTAL FACILITIES

Basic Heat Transfer & Flow Visualization Facility

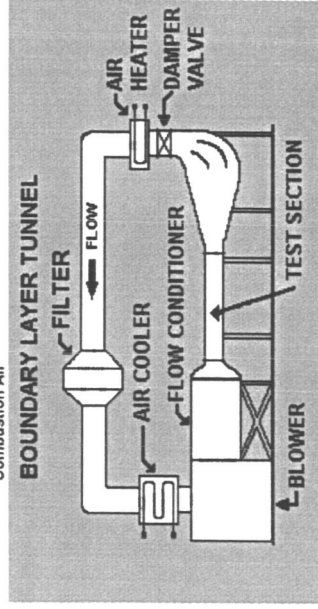


Rotor Wake Rig

Linear Transonic Cascade

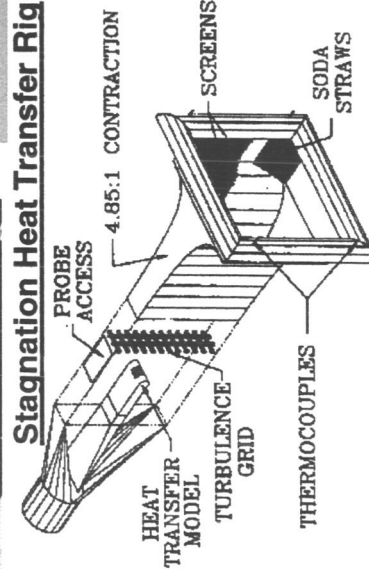


W6A Warm Core Turbine Facility

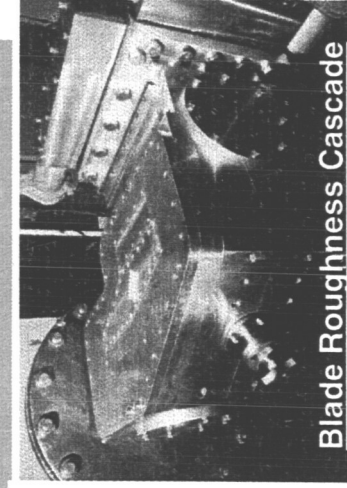


Annular Cascade, Laser Measurements

Stagnation Heat Transfer Rig



Blade Roughness Cascade



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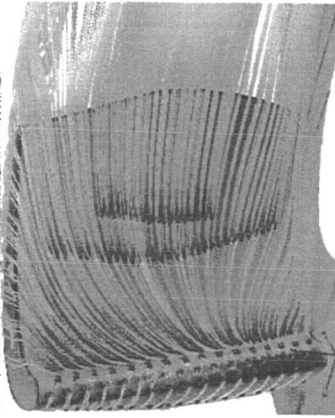
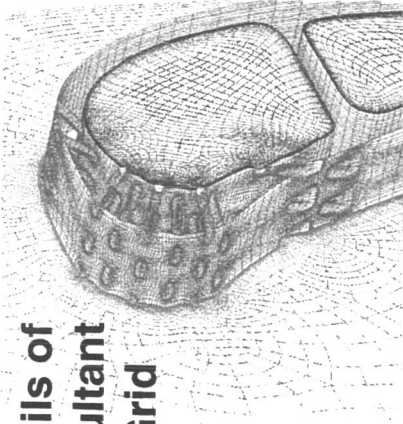




**Grid Block
Topology
for a Typical
Film Cooled
Turbine Blade**

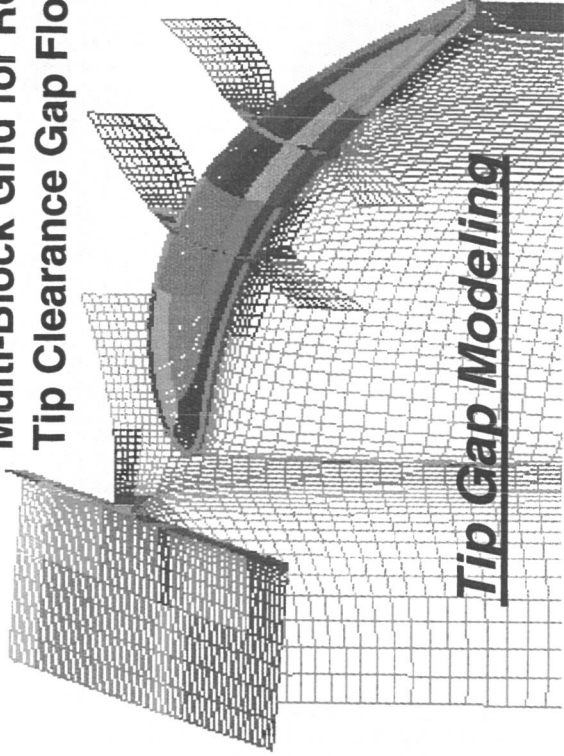
Film Cooling Modeling

**Details of
Resultant
3D Grid**

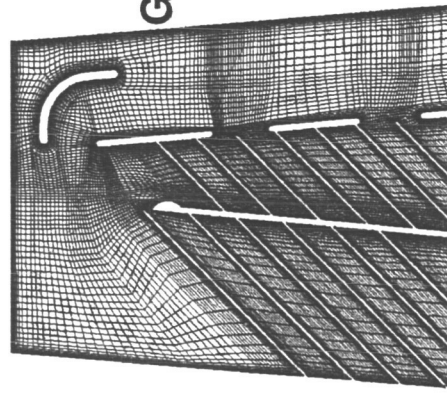


**COMPUTATIONAL MODELING
with the Glenn-HT Code**

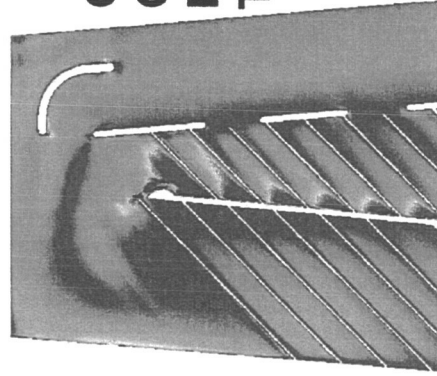
**Multi-Block Grid for Rotor
Tip Clearance Gap Flow**



Tip Gap Modeling

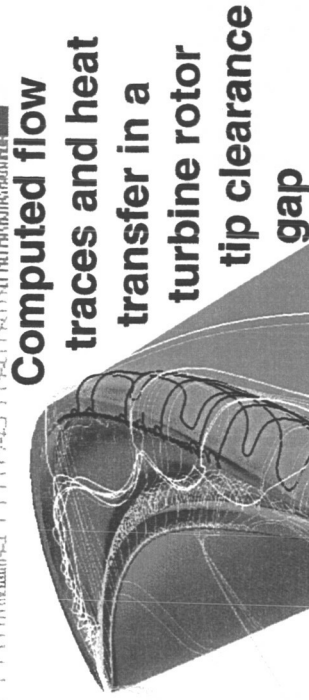


Grid



**Glenn-HT
Computed
Heat
Transfer**

Internal Coolant Passage Modeling



Computed flow

**traces and heat
transfer in a
turbine rotor**

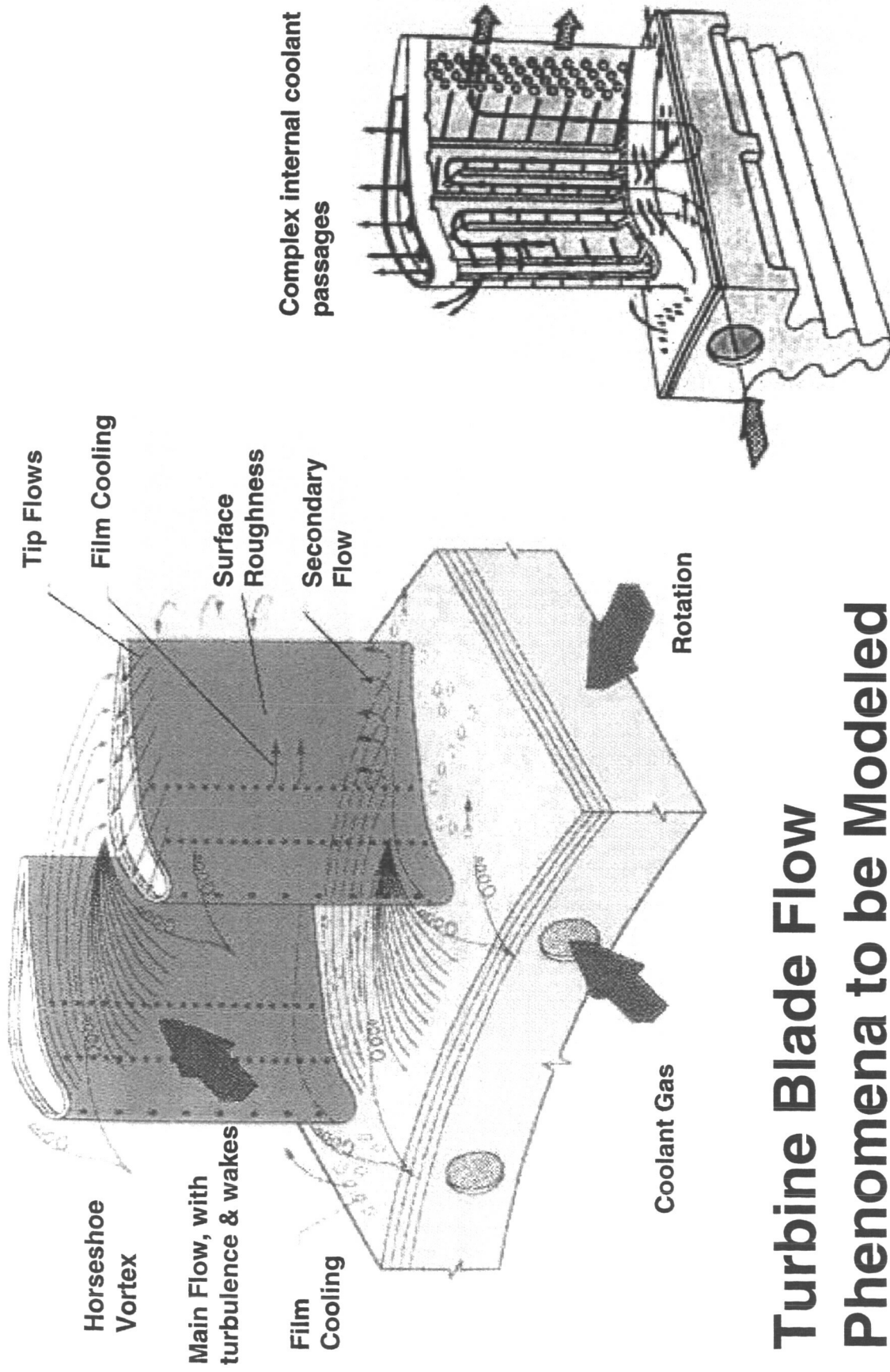
**tip clearance
gap**

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Turbine Blade Flow Phenomena to be Modeled

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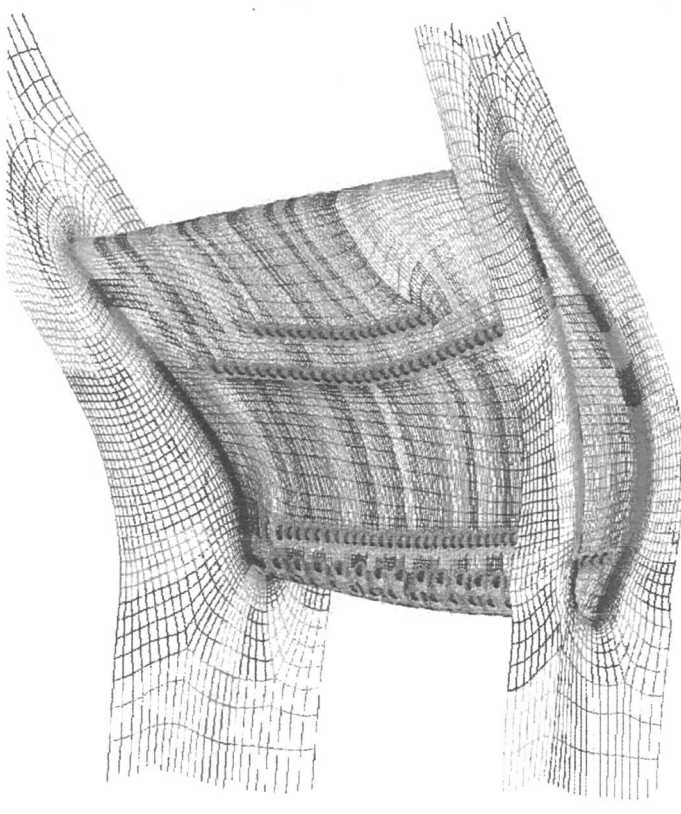
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Glenn-HT: The NASA Glenn Research Center General Multi-Block Navier-Stokes Heat Transfer Code

Background

- Late 1980's, Robert Boyle at NASA Lewis developed near-wall Navier-Stokes CFD tools for modeling heat transfer in the Chima code.
- Prof. A. Arnone (U. of Florence) developed Turbomachinery CFD code with improved grid, TRAF3D, while on sabbatical at NASA Lewis.
- Utility of code for convective heat transfer calculations recognized early, Boyle modeling added by A. Ameri & Arnone.
- Ameri & Arnone add 2-Equation Turbulence model.
- V. Garg adds film cooling modeling.
- E. Steinthorsson creates Multi-Block grid capability (TRAF3D-MB).
- D. Rigby adds internal cooling passage models.
- Originally a modeling research tool, evolved into a design analysis tool.
- Offered to the domestic Turbine Community for evaluation at the DOD/IHPTET 1998 Turbine Engine Technology Symposium, renamed Glenn-HT.



Sample Multi-Block Grid for a Film-Cooled Turbine Rotor Blade

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Capabilities of Glenn-HT

Accurate, efficient 3D analysis of flow & heat transfer in turbomachinery

- Multi-block grid systems for handling complex geometries.
 - Arbitrary index orientations & multiple patches on each grid face.
 - Globally unstructured assembly of blocks-
 - Great flexibility for modeling complex geometries.
 - Grid generation capability rivals unstructured grids.
- Locally structured (body fitted) grids-
 - Well suited for viscous, near-wall phenomena.
 - Simple array data structures.
- Block merging, using Rigby's Method of Weakest Descent (MWD), to reduce number of blocks & improve efficiency.
- Multi-grid convergence acceleration for computational efficiency
- Finite-volume discretization for computational efficiency
- k- ω Turbulence model, no wall functions

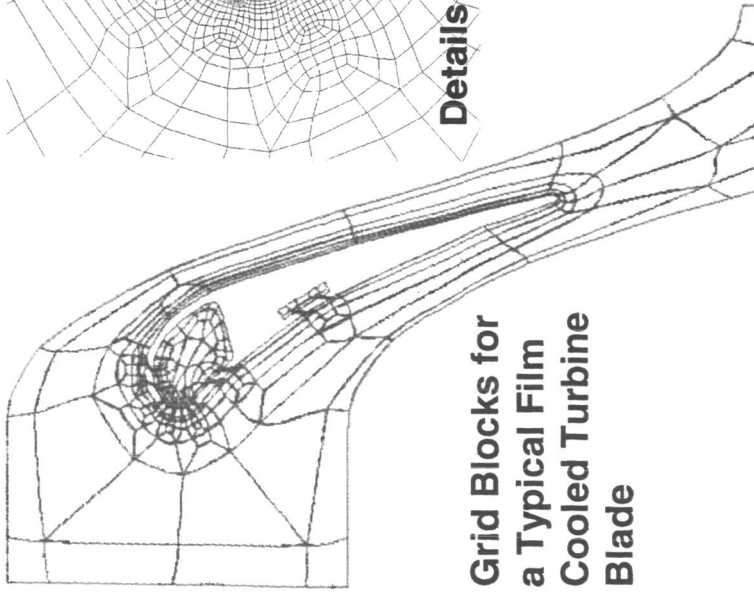
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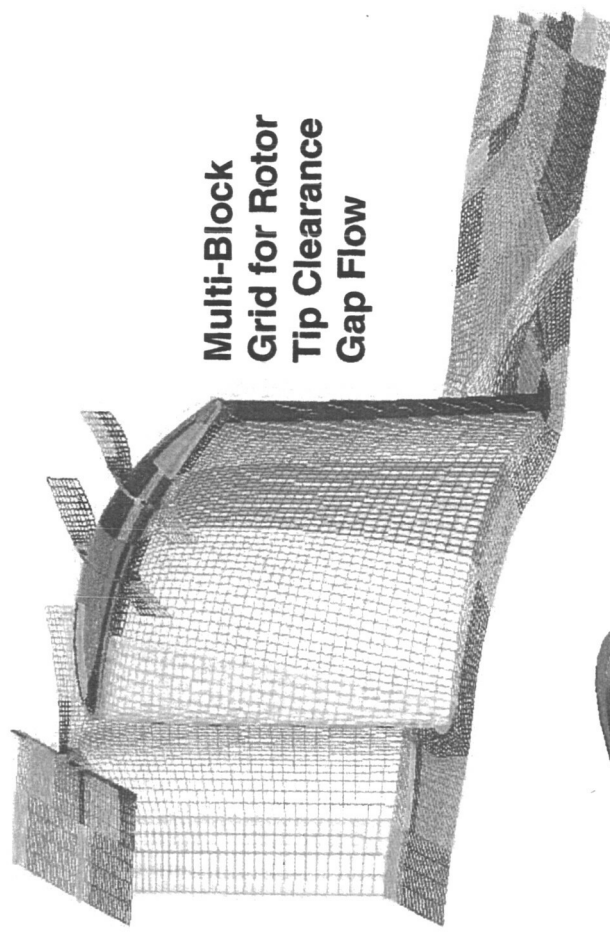
Multi-Block Grid Capability in the Glenn-HT 3-D Navier-Stokes Computer Code Allows Complex Turbomachinery Flow Field Details to be Modeled with a Structured Grid.



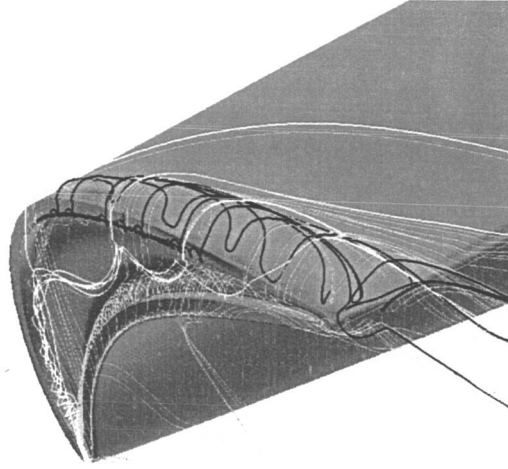
Grid Blocks for
a Typical Film
Cooled Turbine
Blade



Details of Resultant Grid



Multi-Block
Grid for Rotor
Tip Clearance
Gap Flow



Computed
flow traces in
a turbine
rotor tip
clearance
gap

- Multi-Block Topology results in the number of grid points reduced by an Order of Magnitude.
- Resulting grid can be concentrated in critical areas.

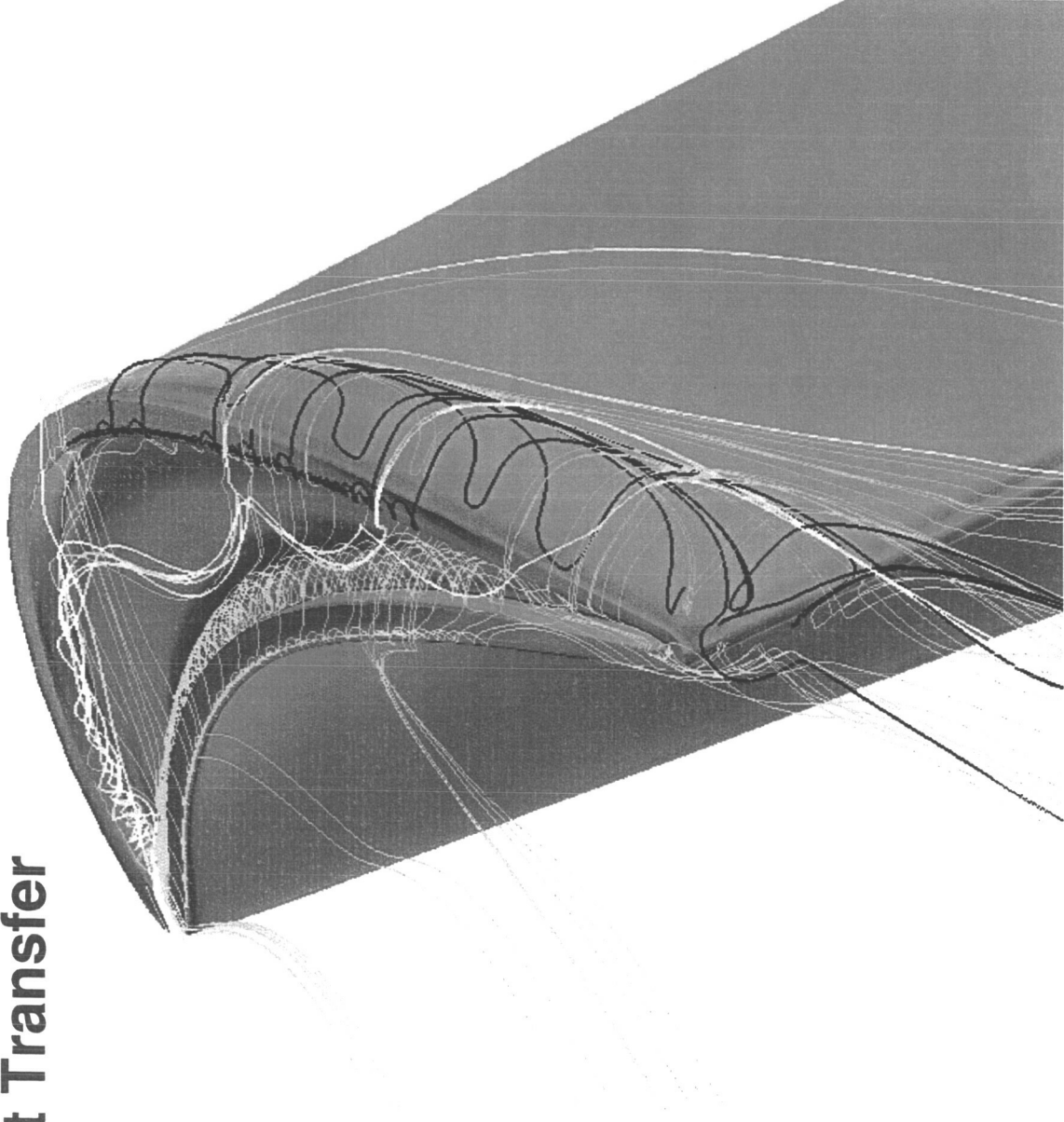
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Glenn-HT Numerical Flow Visualization of Turbine Blade Tip Flow & Heat Transfer



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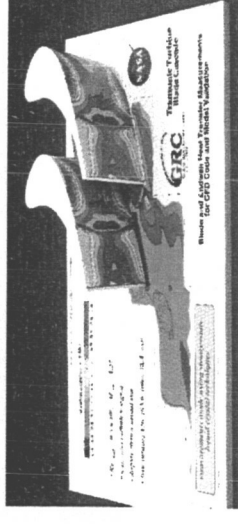
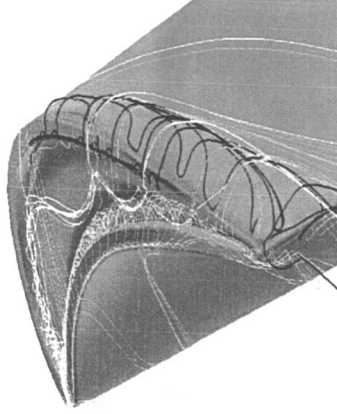
at Lewis Field



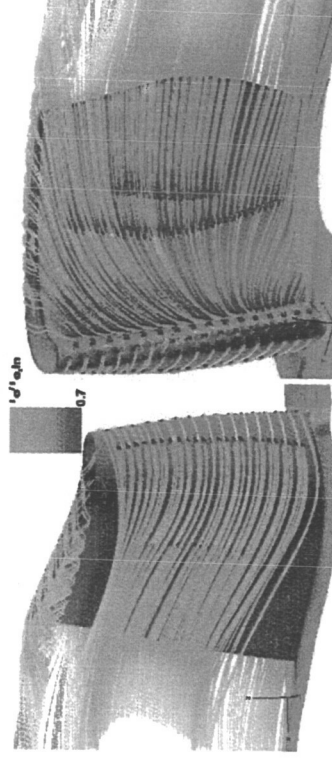
Glenn-HT: The NASA Glenn Research Center General Multi-Block Navier-Stokes Heat Transfer Code

Some Samples of the Range of Code Validation Cases:

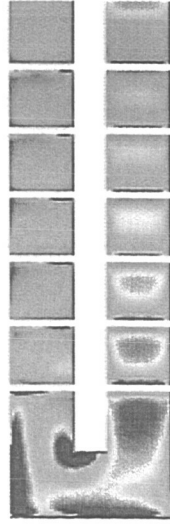
- Heat Transfer in a Transonic Turbine Cascade



- Turbine Tip Leakage Flow and Heat Transfer



- Analysis of Film Cooled Turbine Blade



- Turbine Internal Cooling Passage Analysis

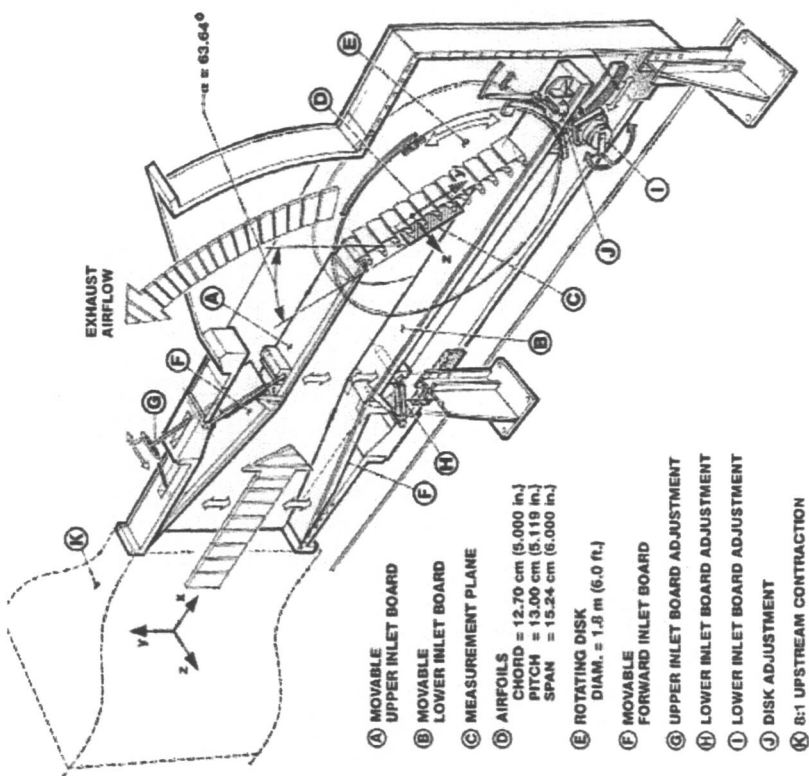
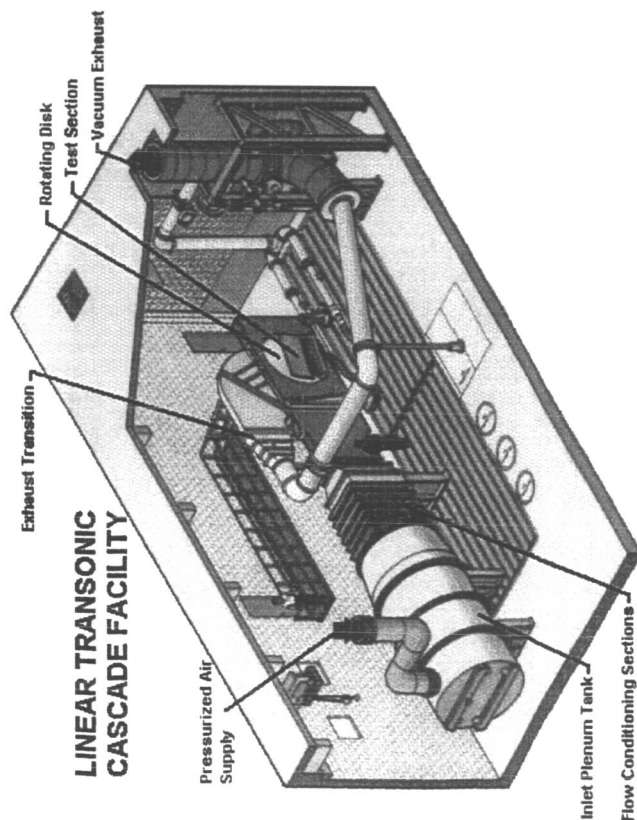
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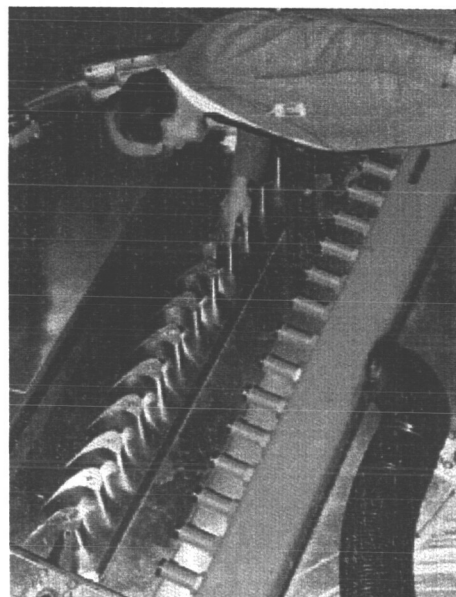
at Lewis Field



LINEAR TRANSONIC CASCADE FACILITY



Exit Mach Number: Up to 1.33
Reynolds Number: 500,000 to 1,000,000
Inlet Angle Variable, -30° to $+15^\circ$
Design Turning Angle: 136°



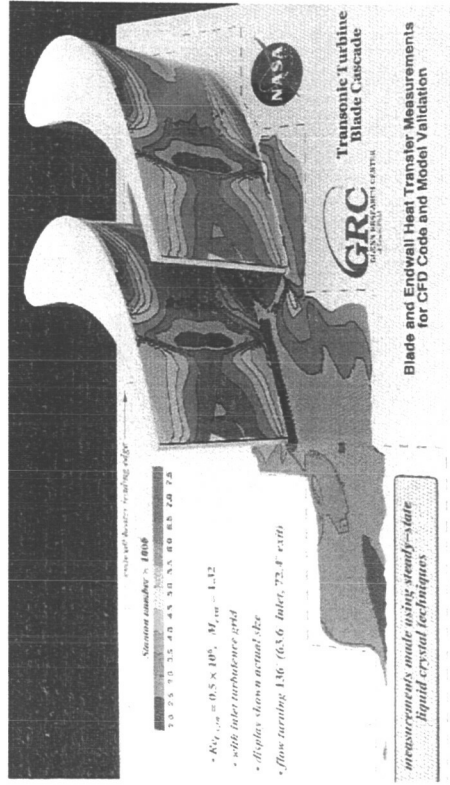
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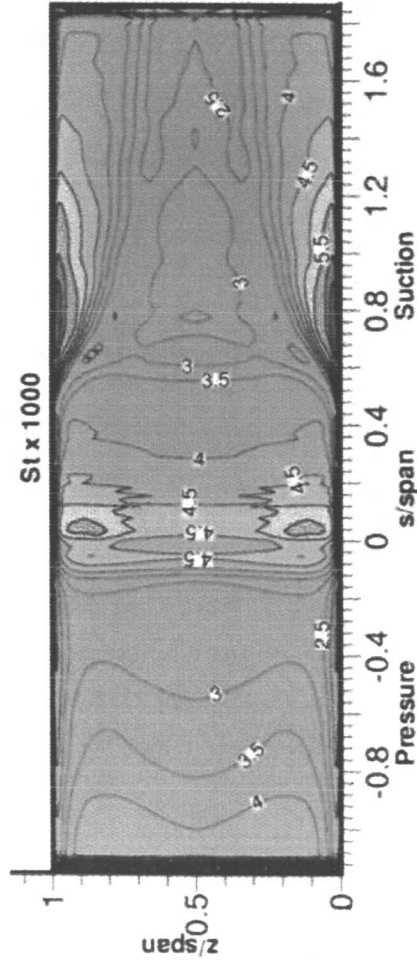
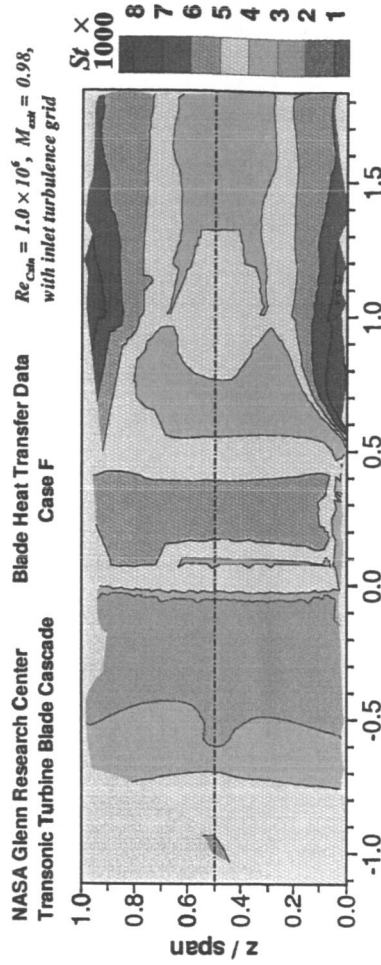
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Glenn-HT Validation - Heat Transfer in a Transonic Turbine Cascade



Experimental Heat Transfer Data from NASA Glenn Transonic Turbine Cascade Rig



Glenn-HT Computed Heat Transfer, using the Shear Stress Transport (SST) Turbulence Model

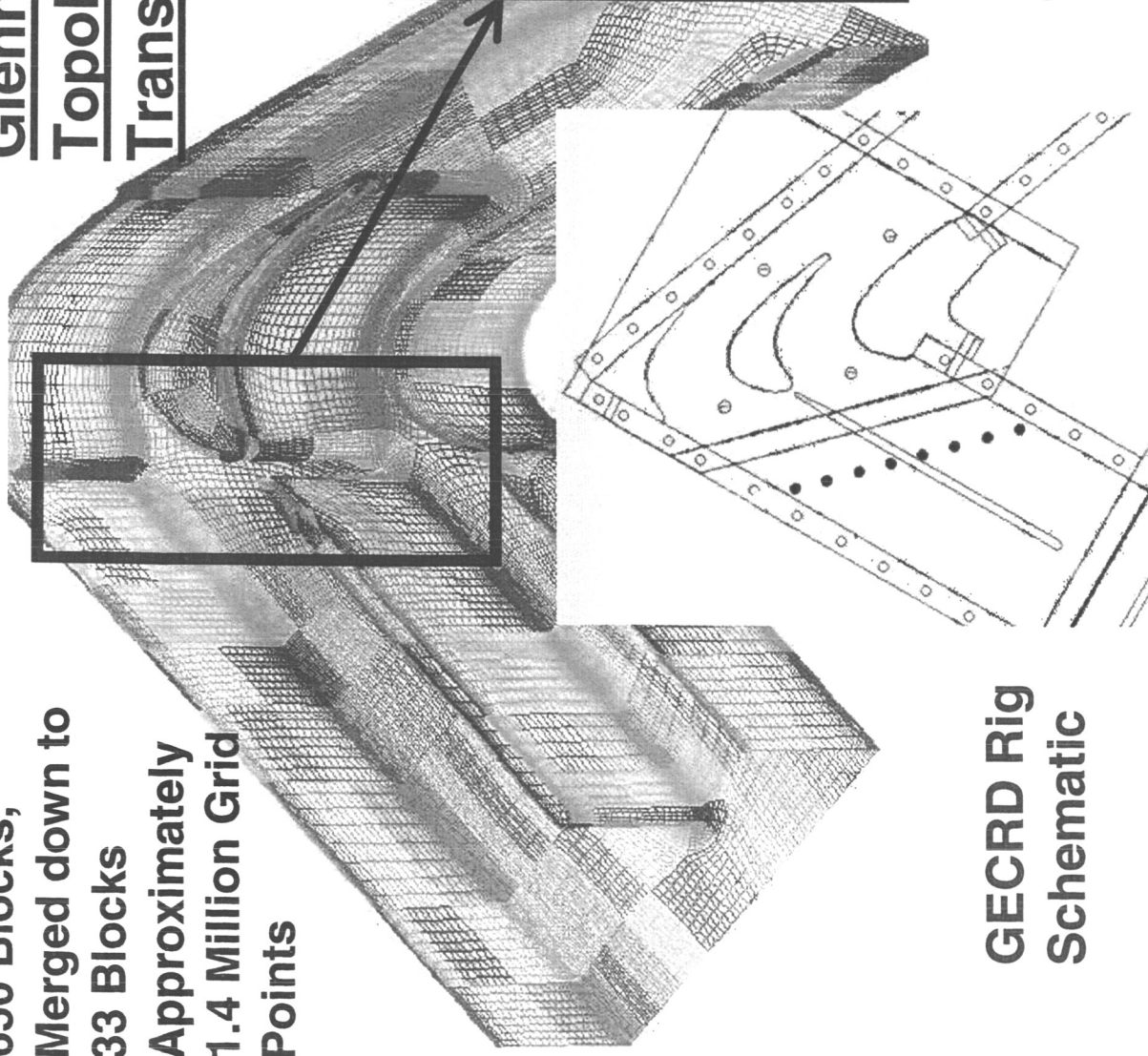
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Glenn-HT Computational Grid Topology for GECRD Tip Heat Transfer Experiment

- 650 Blocks,
Merged down to
33 Blocks
- Approximately
1.4 Million Grid
Points



**Grid Details Showing Recess
in Outer Shroud**

**Tip Gap is 2.03mm, Blade Height
is 101.6mm, (Gap = 2%)**

**GECRD Rig
Schematic**

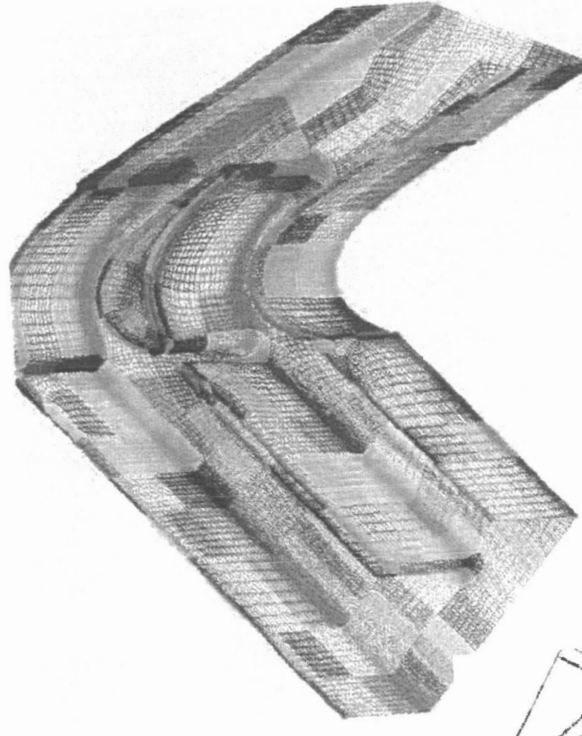
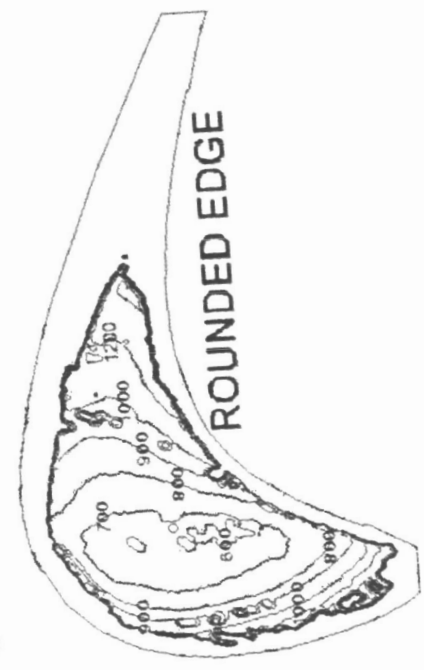
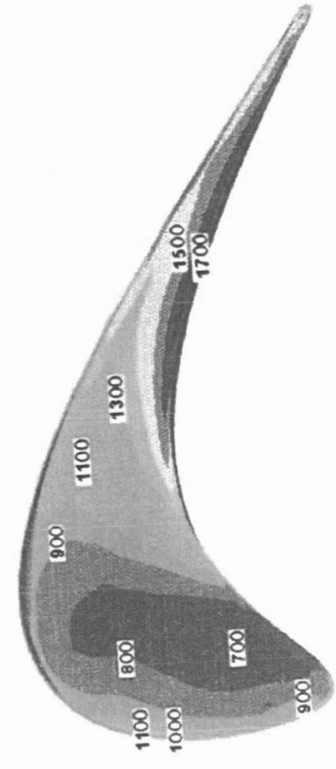
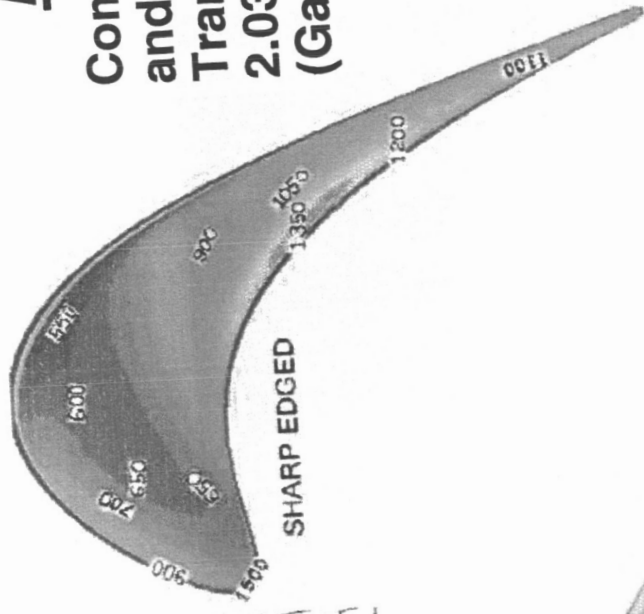
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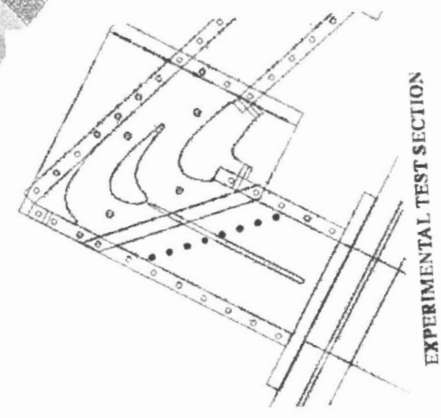
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Blade Tip Heat Transfer

Comparison of GECRD Experiment and Glenn-HT Computation of Heat Transfer Coefficient. Tip Gap is 2.03mm, Blade Height is 101.6mm, (Gap = 2%)



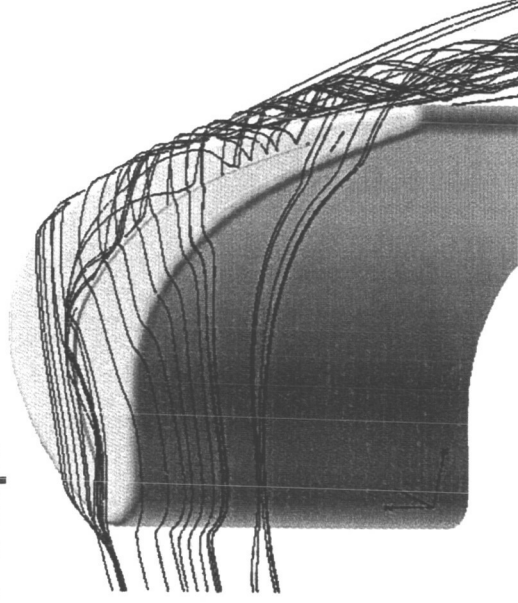
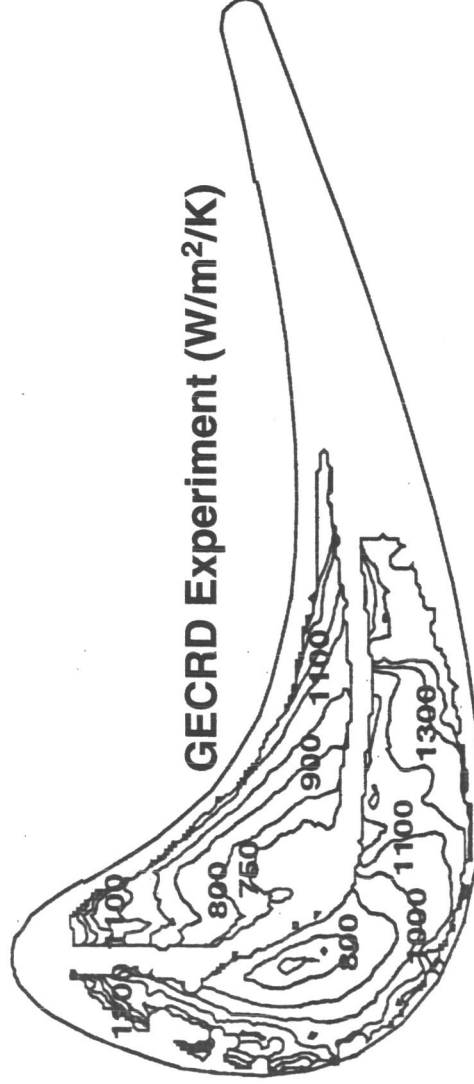
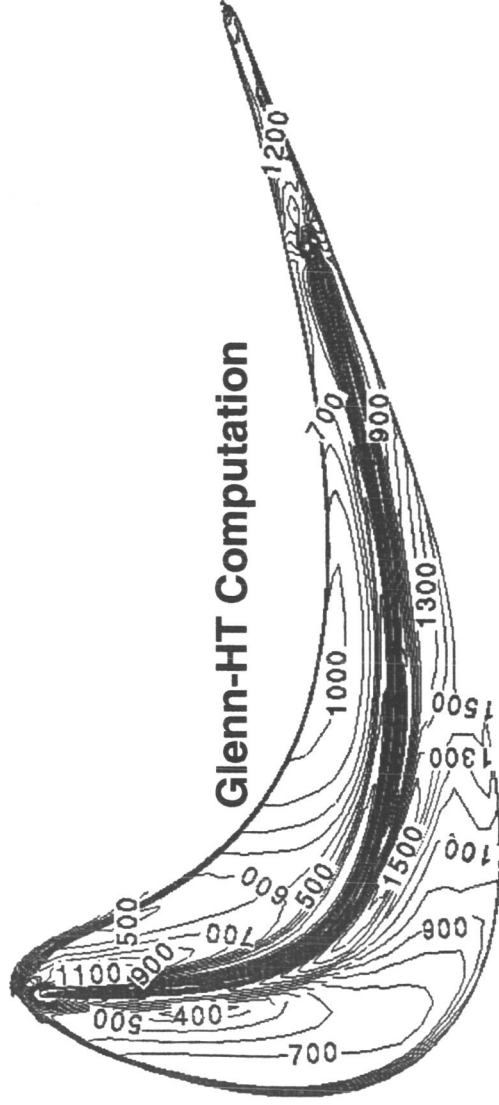
- 650 Blocks, Merged down to 33 Blocks
- Approximately 1.4 Million Grid Points



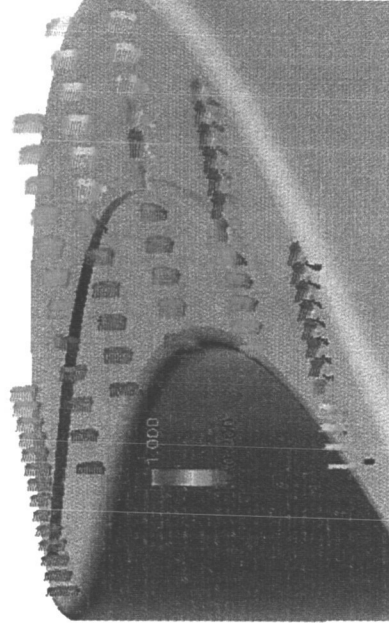
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Blade Tip Heat Transfer

Comparison of Glenn-HT Computation and GECRD Experiment of Heat Transfer Coefficient over a Blade Tip with a Mean-Camberline Strip.



Computed Streamlines



Computed Velocity Profiles

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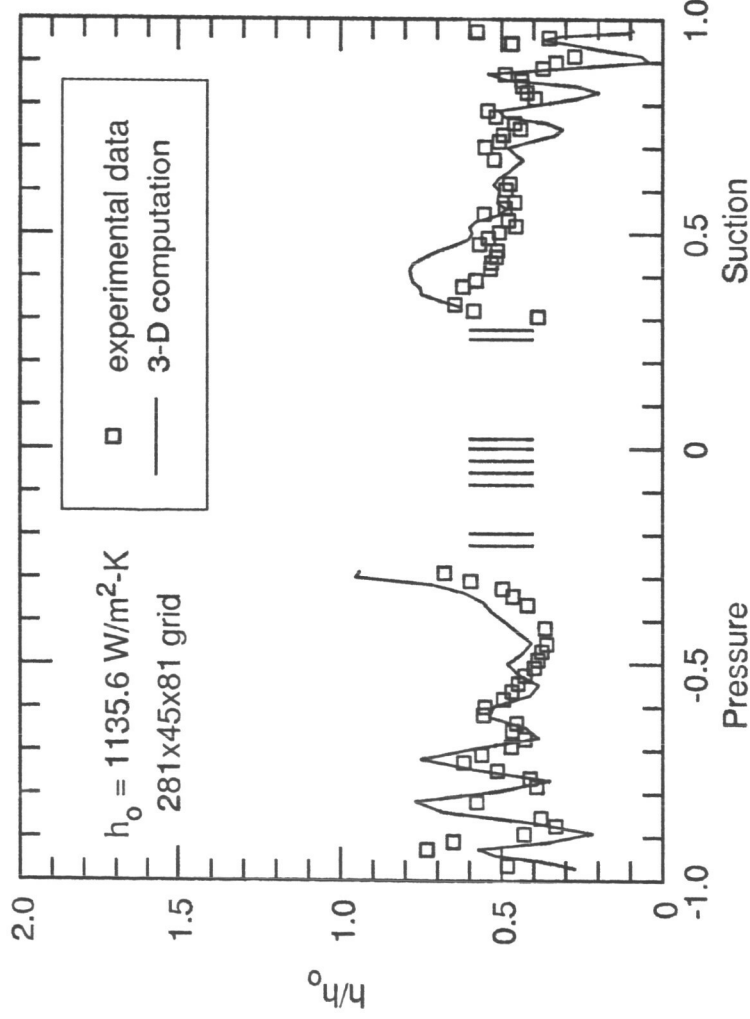
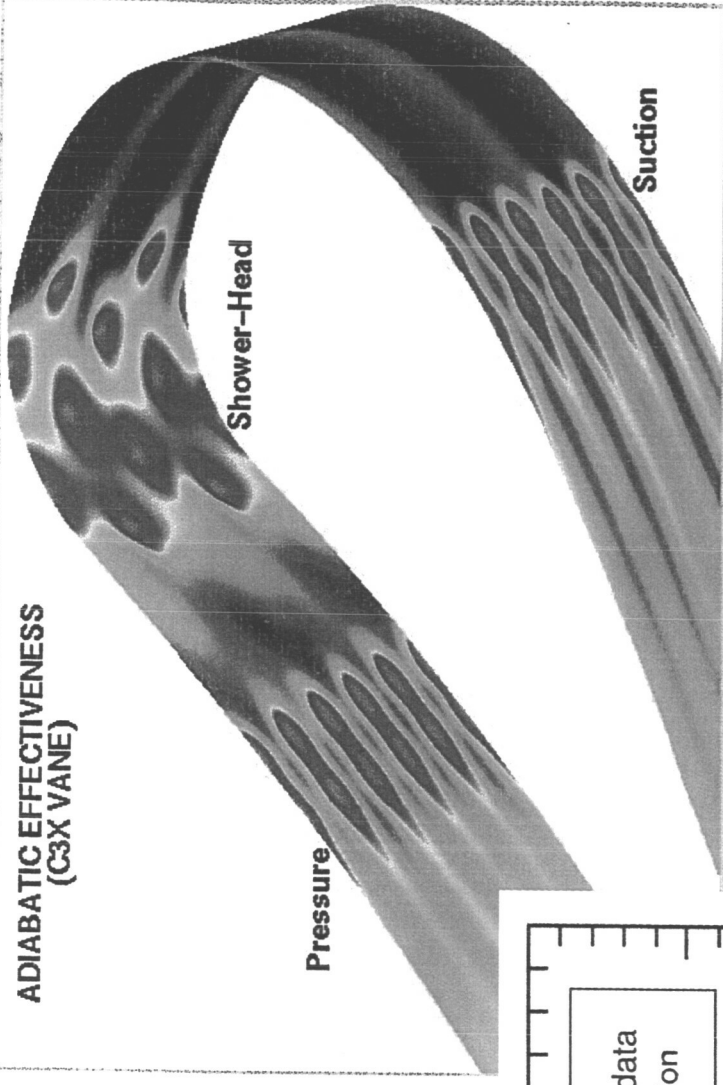
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Heat Transfer in Film-Cooled Turbine Blades

ADIABATIC EFFECTIVENESS
(C3X VANE)



Comparison of measured mid-span heat transfer coefficient on the Allison C3X vane (Hylton et al, 1988) and Glenn-HT CFD results (Garg & Gaugler, 1994)

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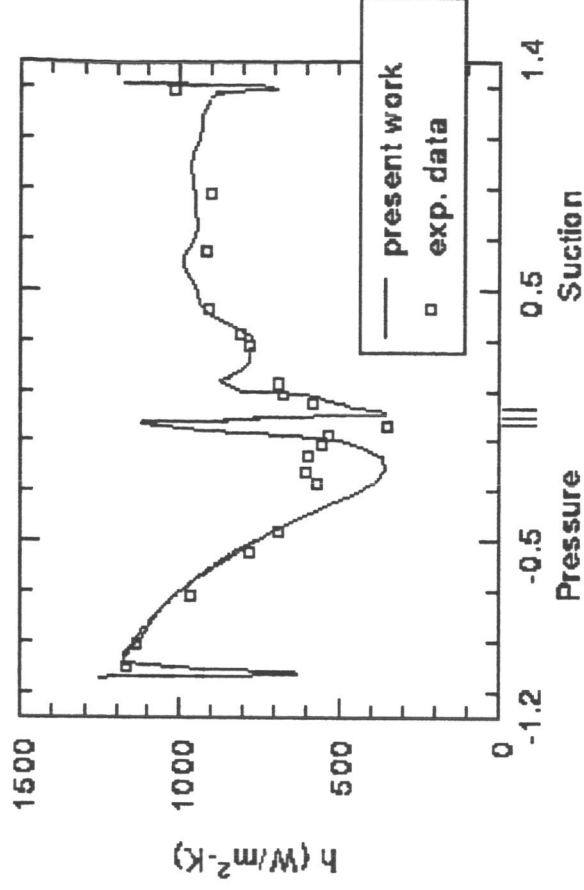
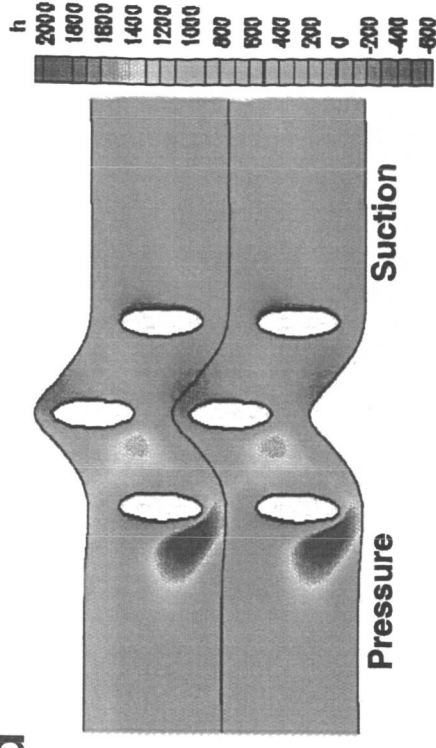
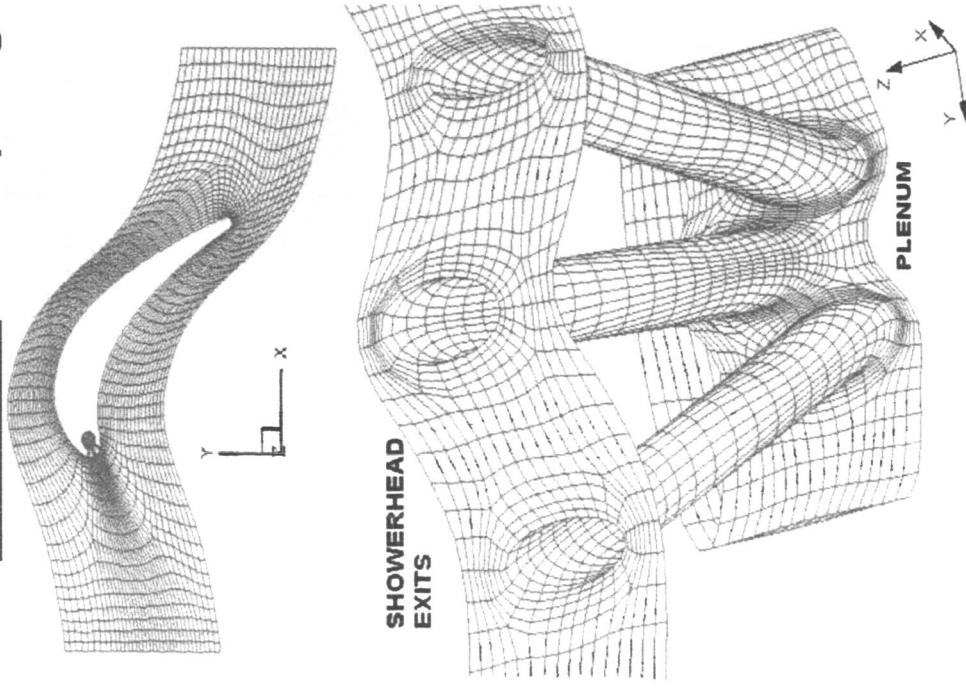
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Heat Transfer in Film-Cooled Turbine Blades

Comparison of measured span-averaged heat transfer coefficient (Camci & Arts, VKI, 1985) and CFD computation using the Glenn-HT code (Garg & Rigby, 1998)



Case 154: $M_{ex} = .905$, $Re_{c,in} = 8.42 \times 10^5$,
 $T_o = 408.9 \text{ K}$, $T_w/T_o = 0.722$, $T_c/T_o = 0.52$

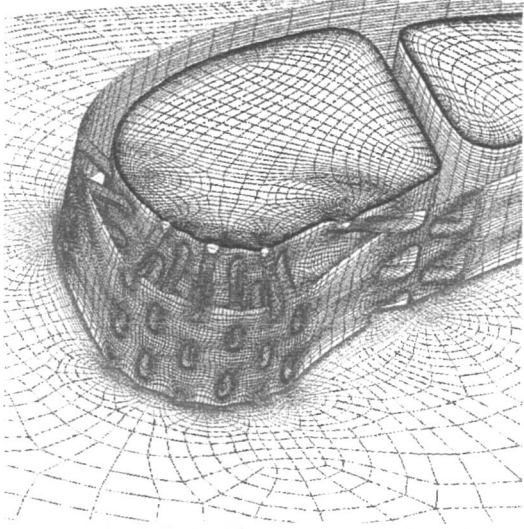
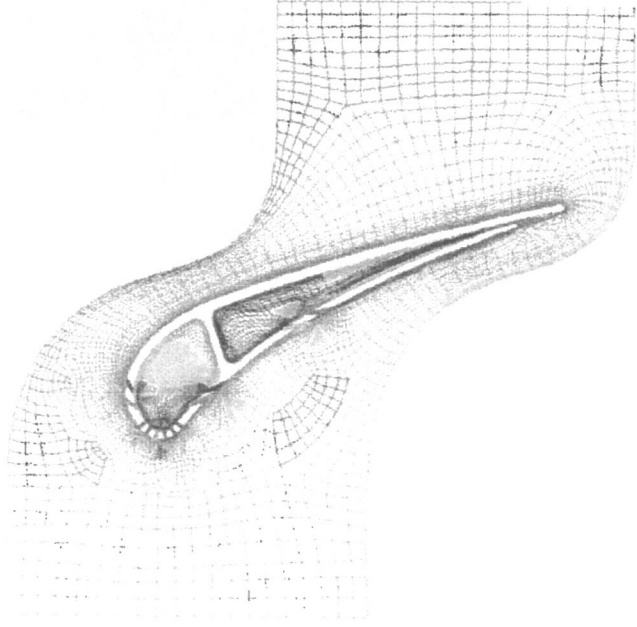


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Glenn-HT 3D Coupled Internal/External Simulation of a Film-Cooled Turbine Vane



**Glenn-HT Predicted Wall
Heat Flux on Plenum,
Holes, & Vane**

- Realistic film-cooled turbine vane
- Shaped & unshaped holes
- Holes supplied by two plena
- NASA GRC experiment planned
- Glenn-HT code used with 140 merged blocks
- Plena & film hole geometry fully modeled
- 2D design modeled as spanwise periodic

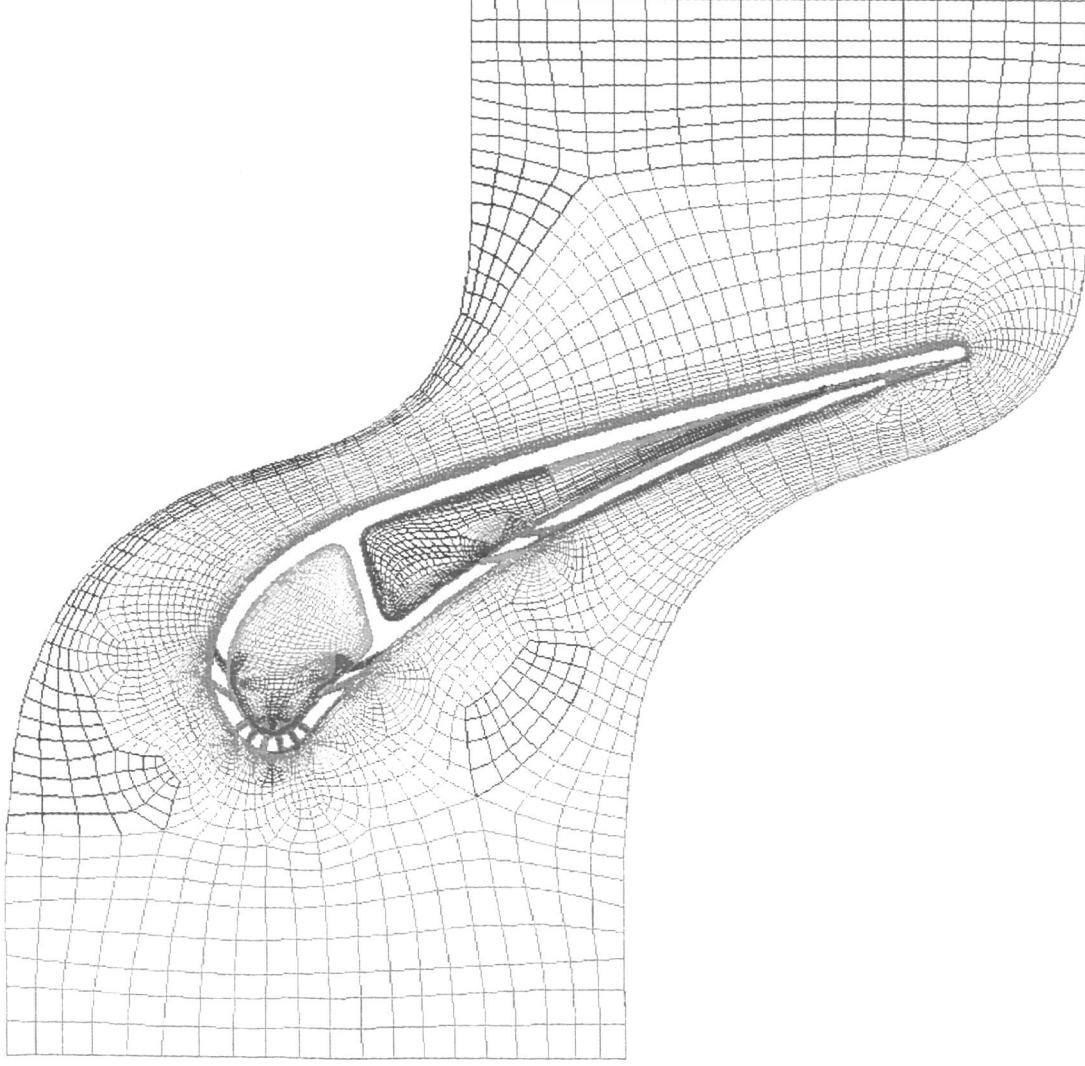
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Glenn-HT 3D Coupled Internal/External Simulation of Film-Cooled Turbine Vane



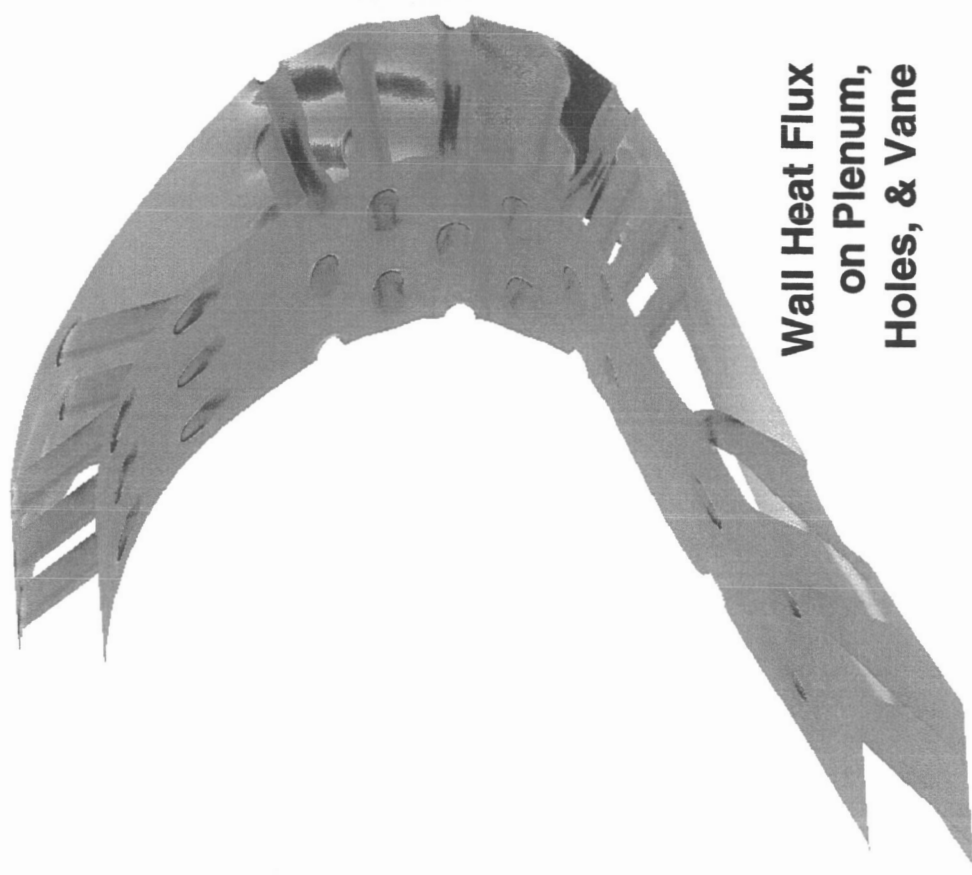
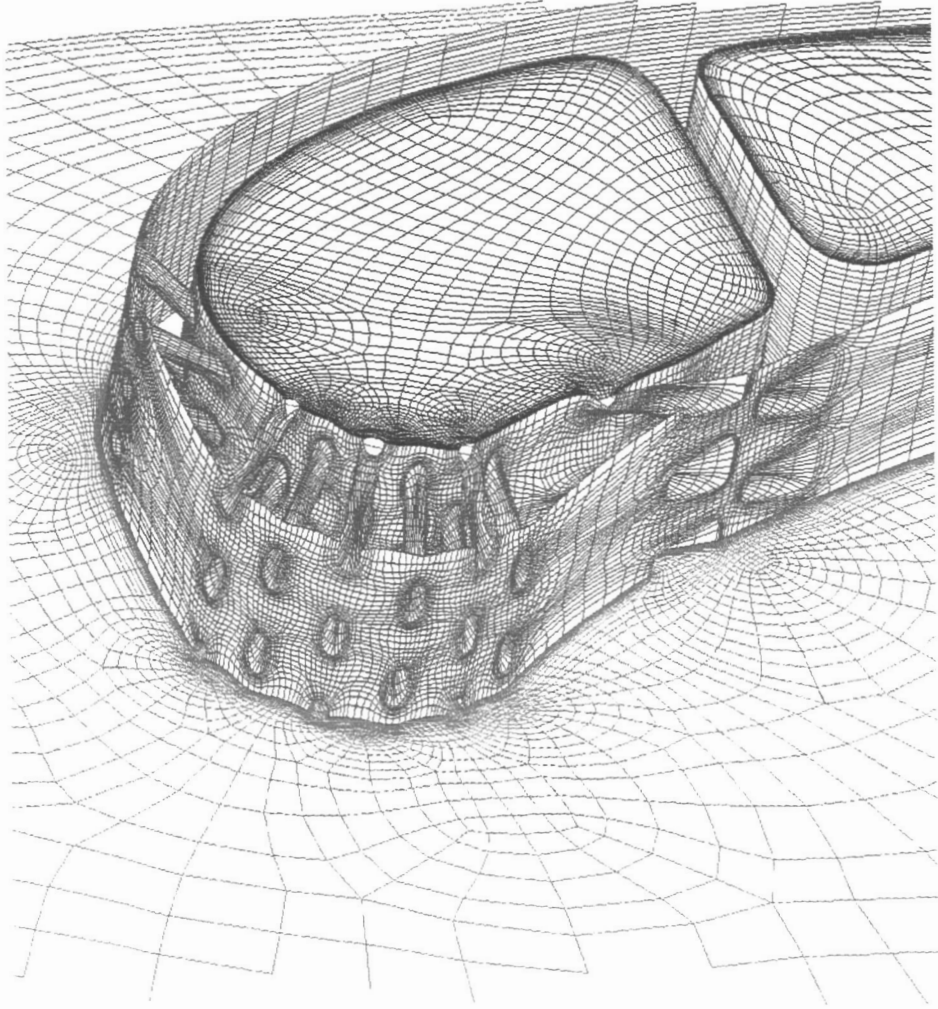
- Realistic film-cooled turbine vane
- Shaped & unshaped holes
- Holes supplied by two plena
- NASA GRC experiment planned
- Glenn-HT code used with 140 merged blocks
- Plena & film hole geometry fully modeled
- 2D design modeled as spanwise periodic

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at Lewis Field

Glenn-HT 3D Coupled Internal/External Simulation of Film-Cooled Turbine Vane



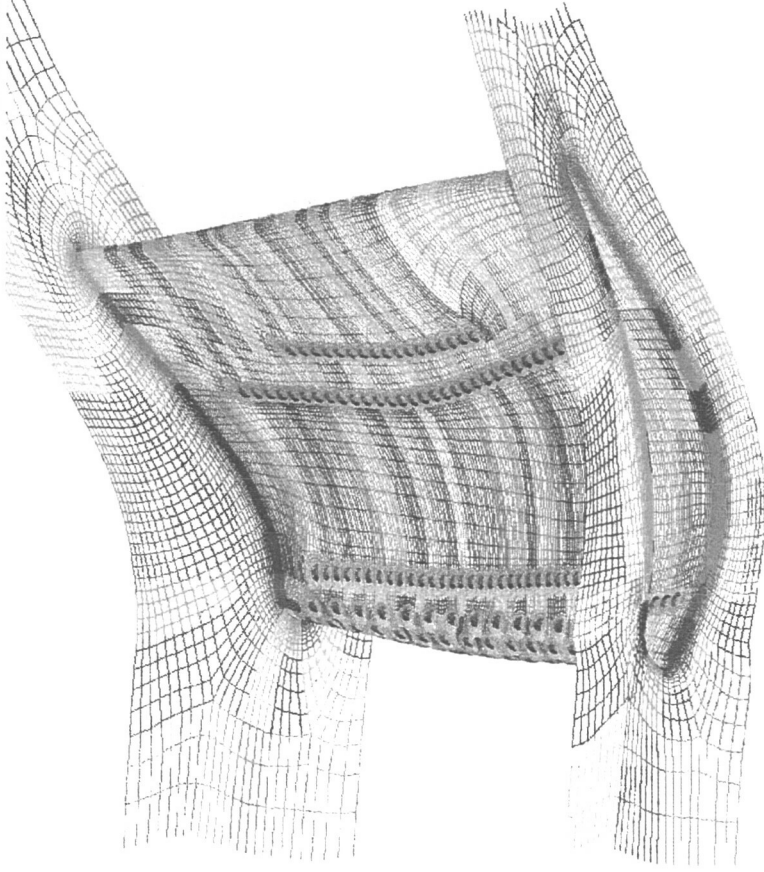
Wall Heat Flux
on Plenum,
Holes, & Vane

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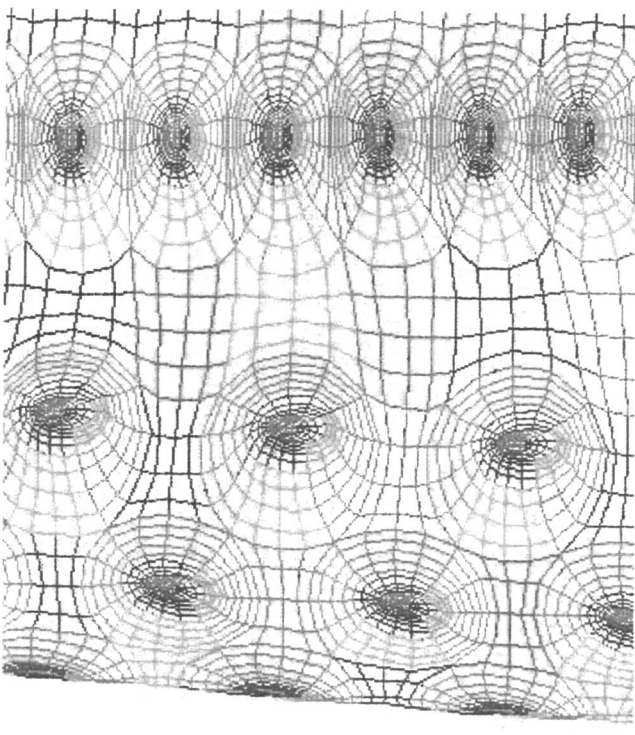


at Lewis Field

Glenn-HT Computation for a Film-Cooled Rotor Blade



Grid details near holes



- Honeywell blade configuration, to be tested at OSU Turbine Lab.
- No span-wise symmetry, so all 172 holes must be gridded, as well as tip clearance gap.
- 80 cells over each hole exit, flow & turbulence boundary condition distributions specified for each hole.
- Over 2.2 million grid cells overall.

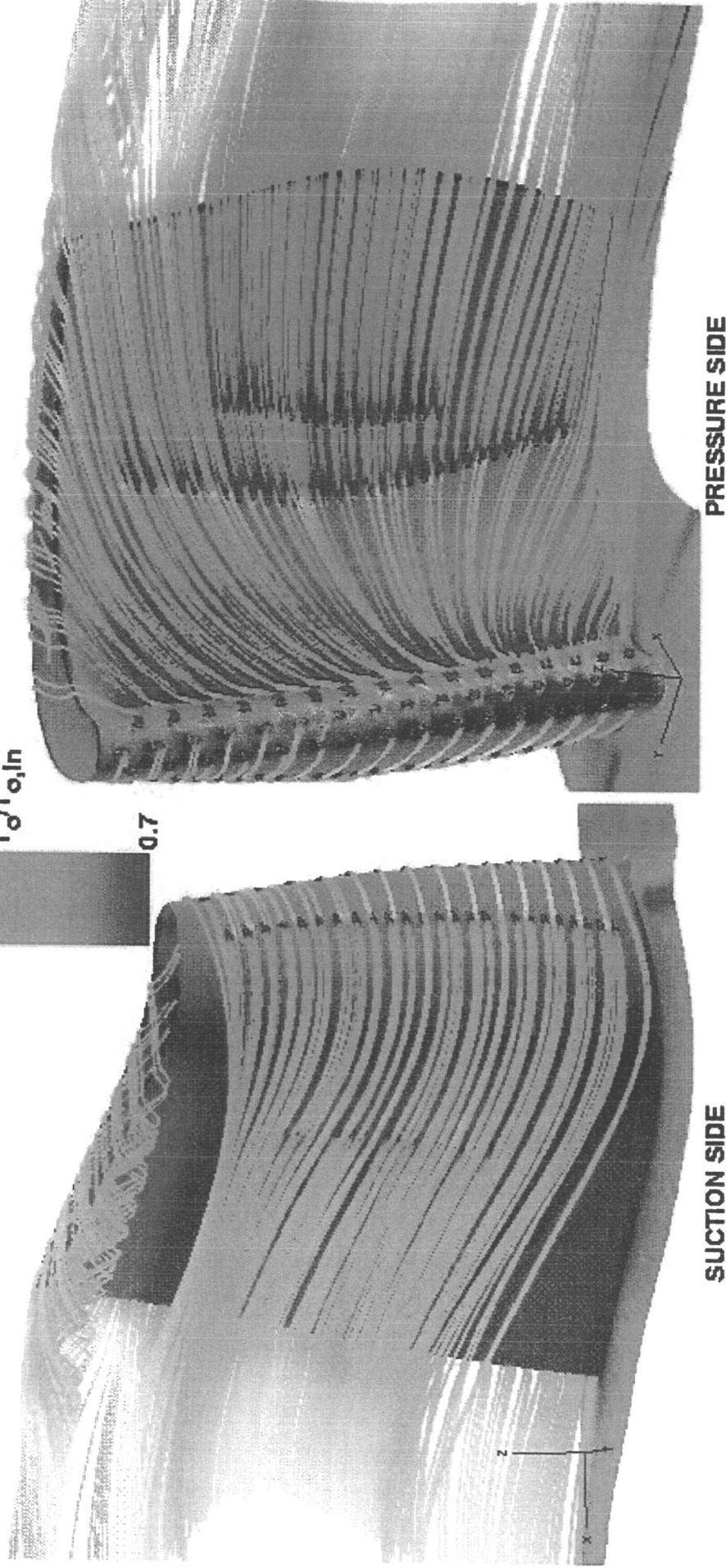
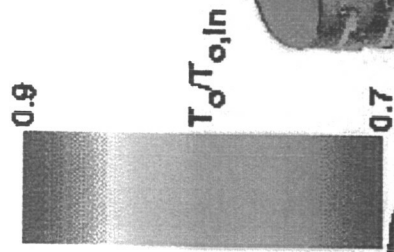
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Glenn-HT Computational Flow Visualization for a Film-Cooled Rotor Blade

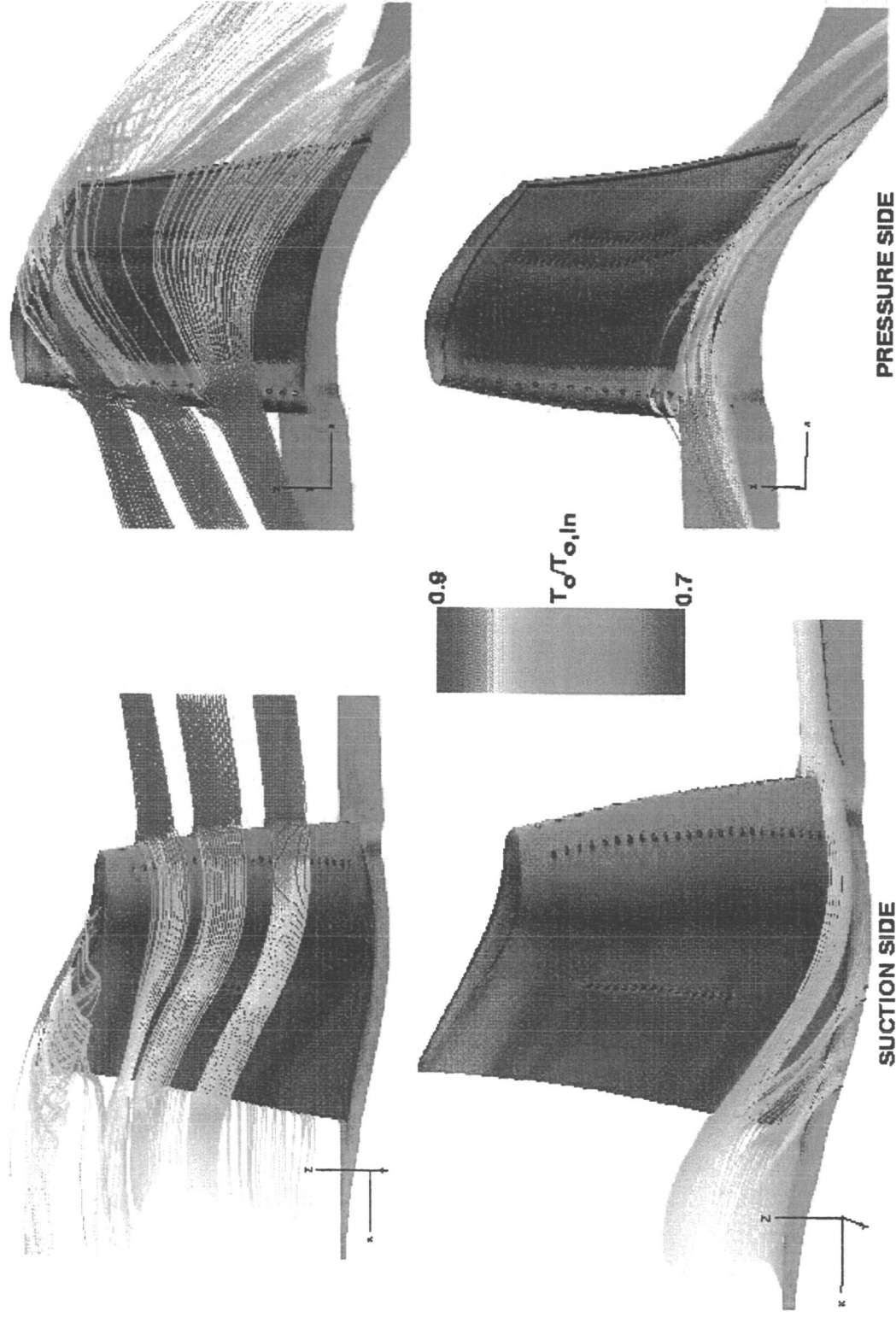


STREAMLINES, COLORED BY TEMPERATURE, EMANATING FROM HOLES OVER THE COOLED BLADE SURFACE
WITH DISTRIBUTION OF h

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Glenn-HT Computational Flow Visualization for a Film-Cooled Rotor Blade



STREAMLINES, COLORED BY TEMPERATURE, OVER THE COOLED BLADE SURFACE WITH DISTRIBUTION OF h

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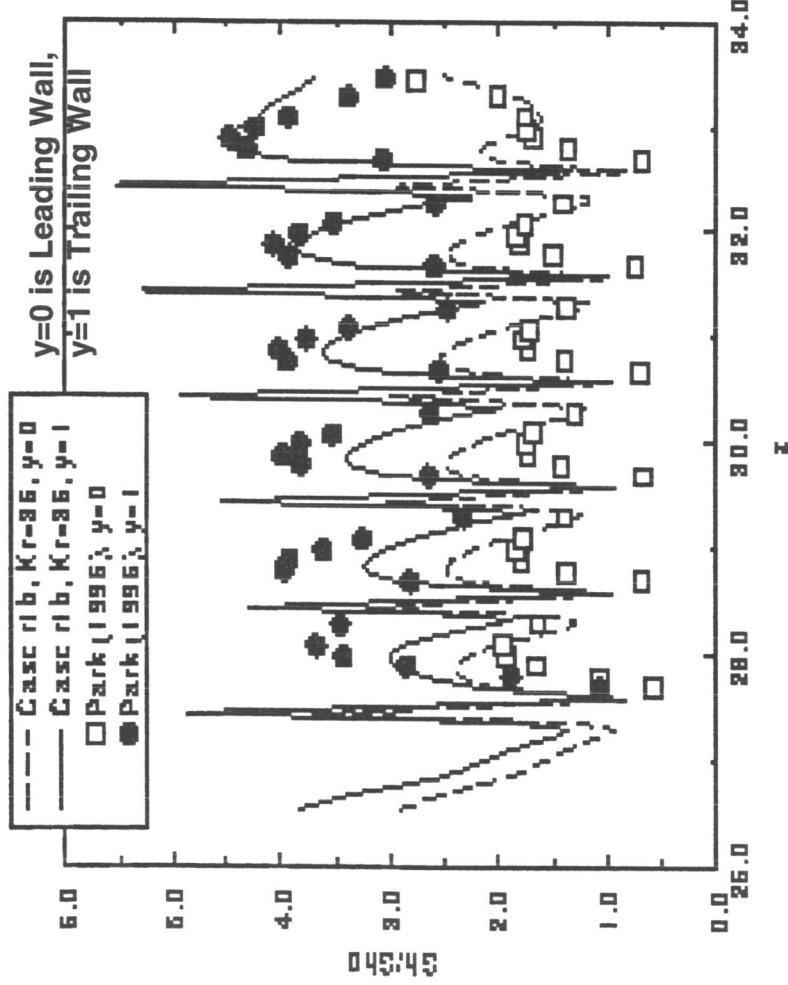
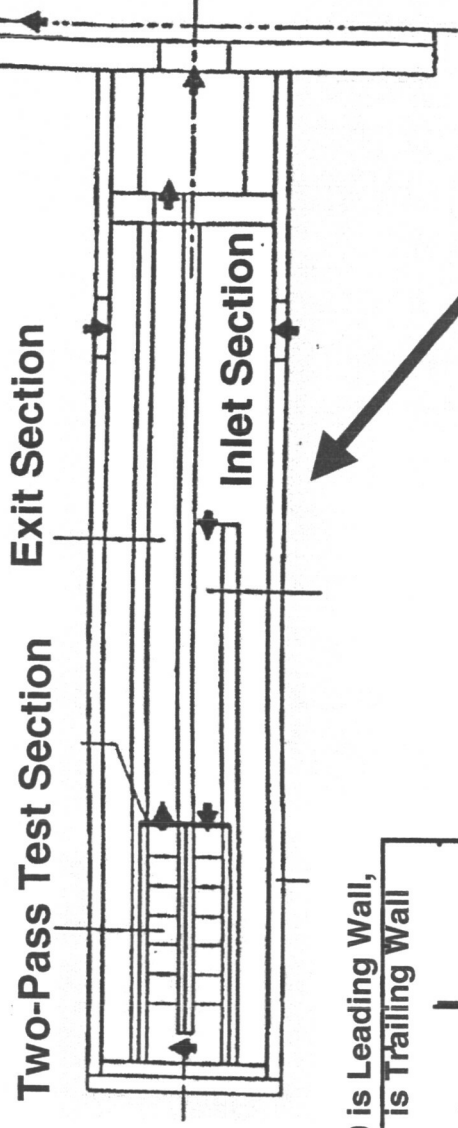
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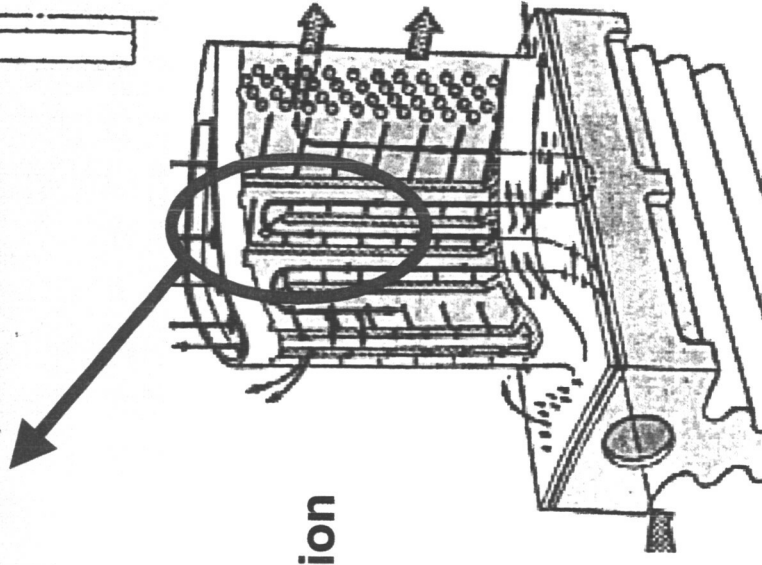


Glenn-HT Prediction of Heat and Mass Transfer in a Rotating Ribbed Coolant Passage with a 180° Turn

Experiment of Park et al
(1996)



Glenn-HT
Computation
by Rigby,
1998



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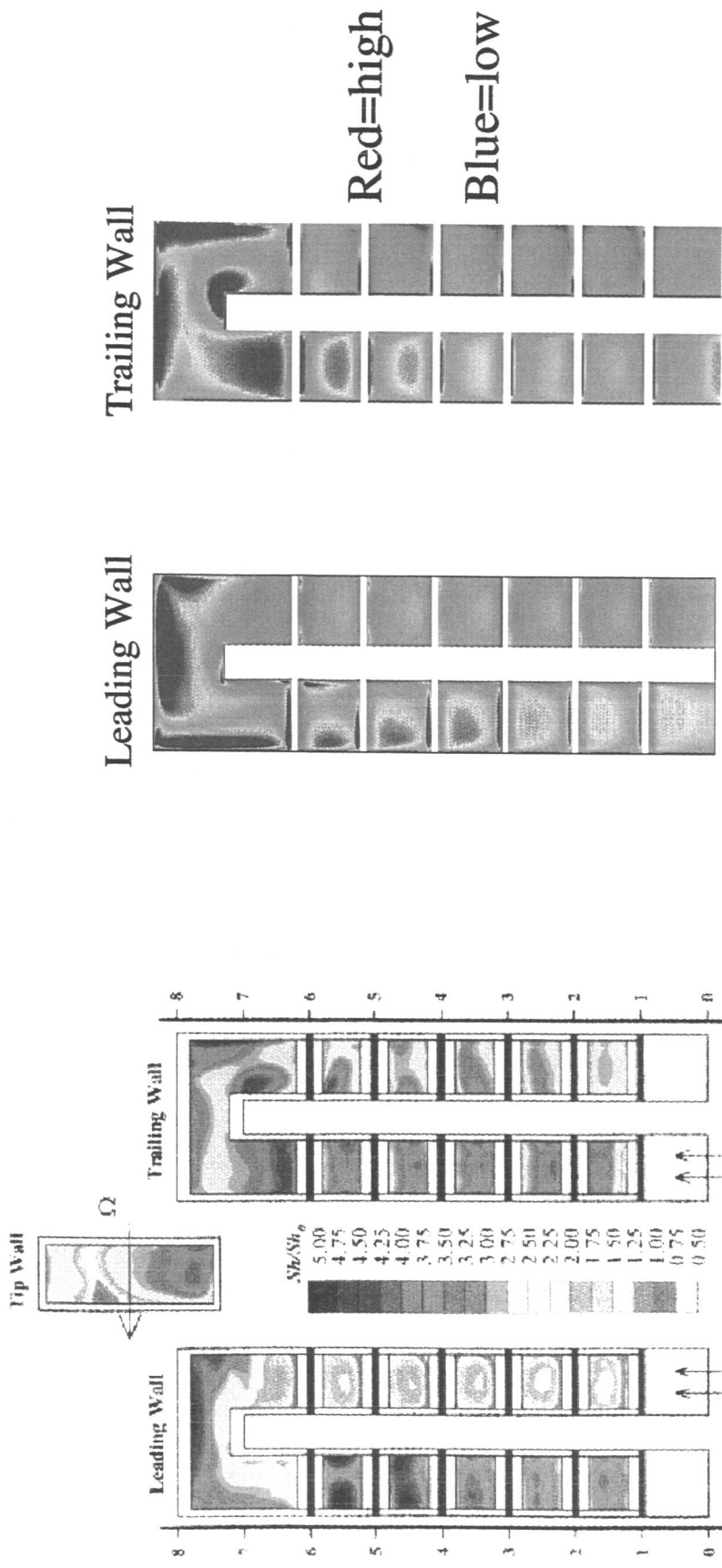
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Glenn-HT Internal Cooling Passage Modeling

(Rotating Channel with 180° turn & ribs)

Normalized Sherwood No.



Experiment of Park et al (1996)

Glenn-HT Computation

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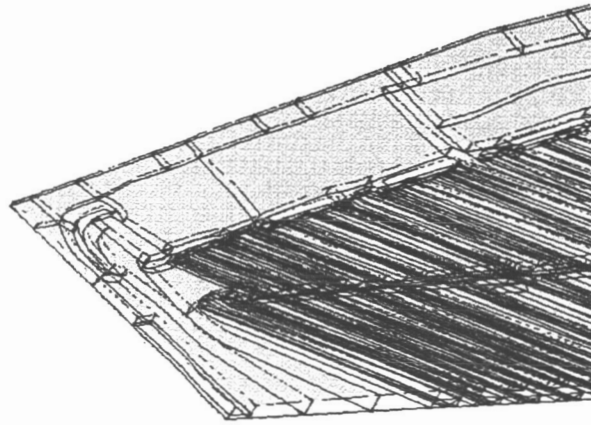
TURBINE BRANCH



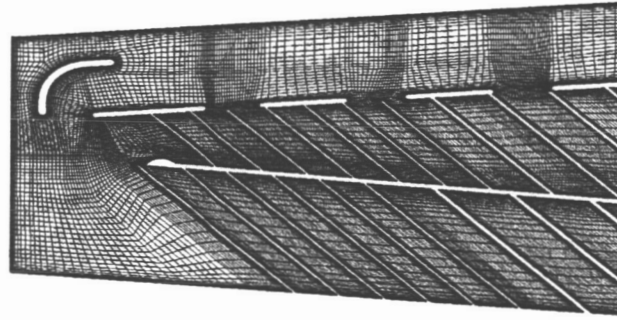
at Lewis Field

Glenn-HT 3D heat transfer computations compared to experimental data near the turn in a complex turbine blade trailing edge cooling passage.

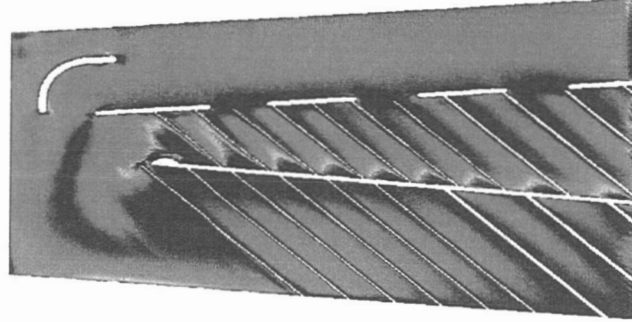
Computation used a grid of 4.5 million cells and was run using 32 processors on an SGI Origin Cluster.



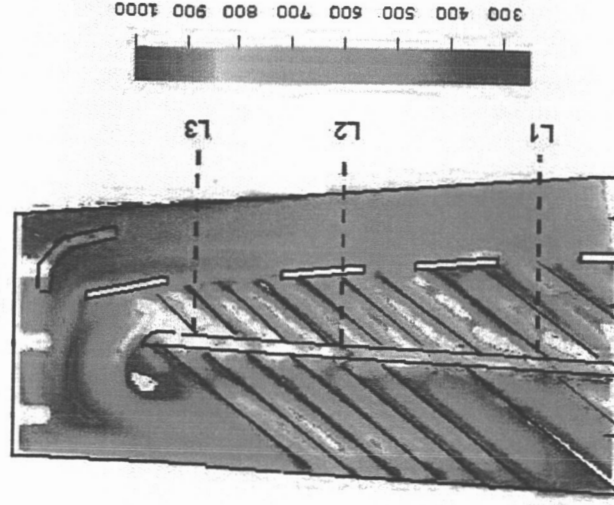
**Grid Block
Topology**



**Computational
Surface Grid**



**Computed
Heat Transfer**



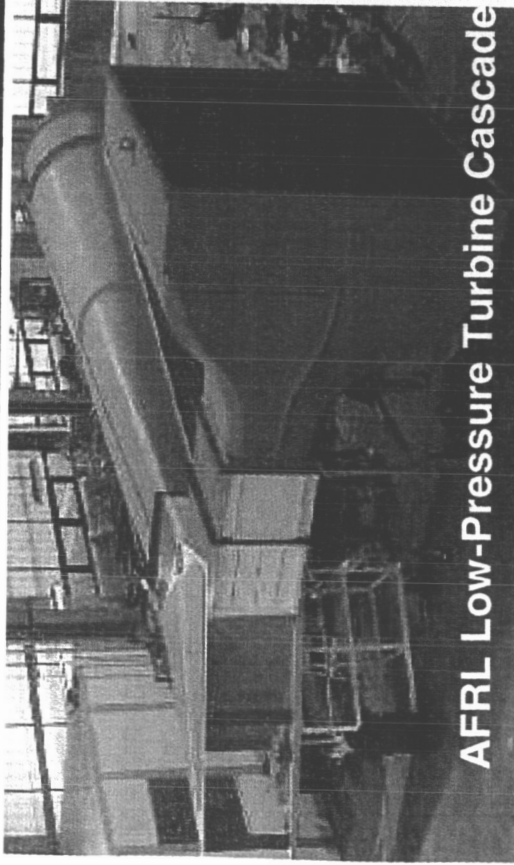
**GE Measured
Heat Transfer**

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Glenn-HT Simulation of AFRL Flow Control Test

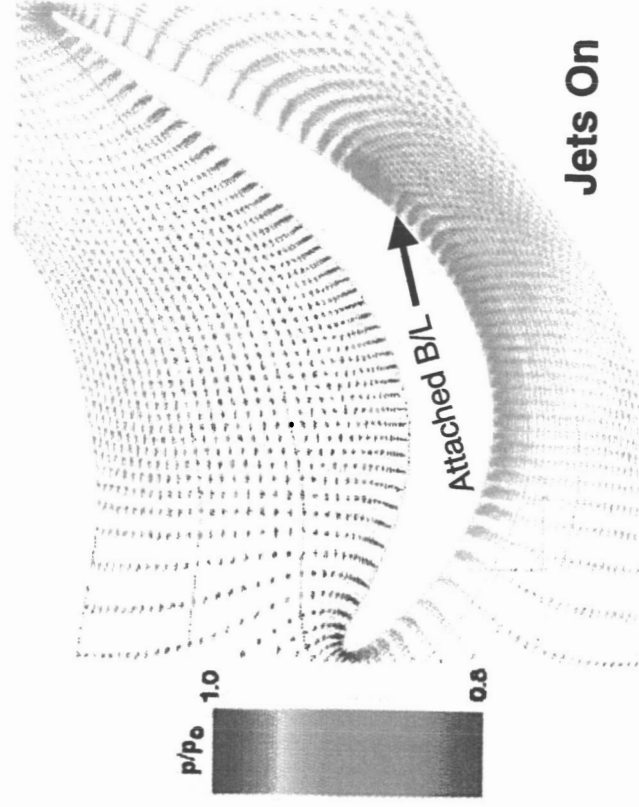
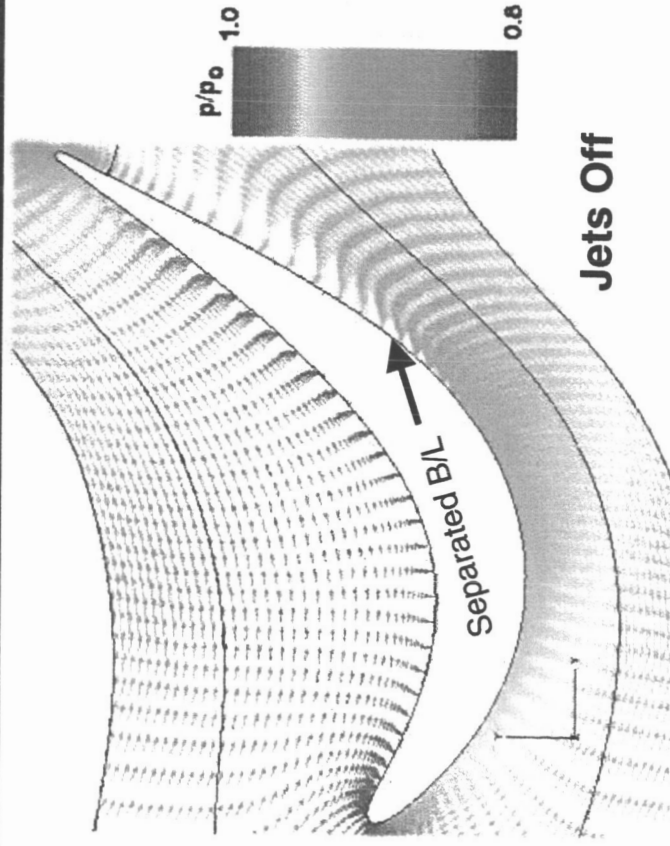


Low Pressure Turbine (LPT) Blade tested at Air Force Research Lab (AFRL)

- Low Reynolds and Mach numbers
- Boundary Layer separation on the suction side.
- Vortex generator jets (VGJ) on the blade surface induce vortices in the boundary layer upstream of the separation zone, re-energizing the boundary layer and making it resistant to separation

Glenn-HT code run with and without the VGJ

- Excellent agreement with experiment



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Glenn-HT: The NASA Glenn Research Center General Multi-Block Navier-Stokes Heat Transfer Code

Future Direction

- **Unsteady vs Quasi-Steady**
- **Conjugate Heat Transfer Analysis**
- **Turbulence Model Improvements**
- **Automated Topology Generation**

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Glenn-HT: The NASA Glenn Research Center General Multi-Block Navier-Stokes Heat Transfer Code

SUMMARY

- Glenn-HT History
- Glenn-HT Capabilities
- Glenn-HT Sample Validation Cases
- Glenn-HT Future Direction

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